The Boyd Orr Centre
for Population and Ecosystem Health

From Epidemic to Elimination: Density-Vague Transmission and the Design of Mass Dog Vaccination Programs

Dan Haydon

University of Glasgow

Daniel.Haydon@glasgow.ac.uk

Sunny Townsend

Katie Hampson

Sarah
Cleaveland

Tiziana
Lembo

Background

More that 55,000 people die of rabies each year

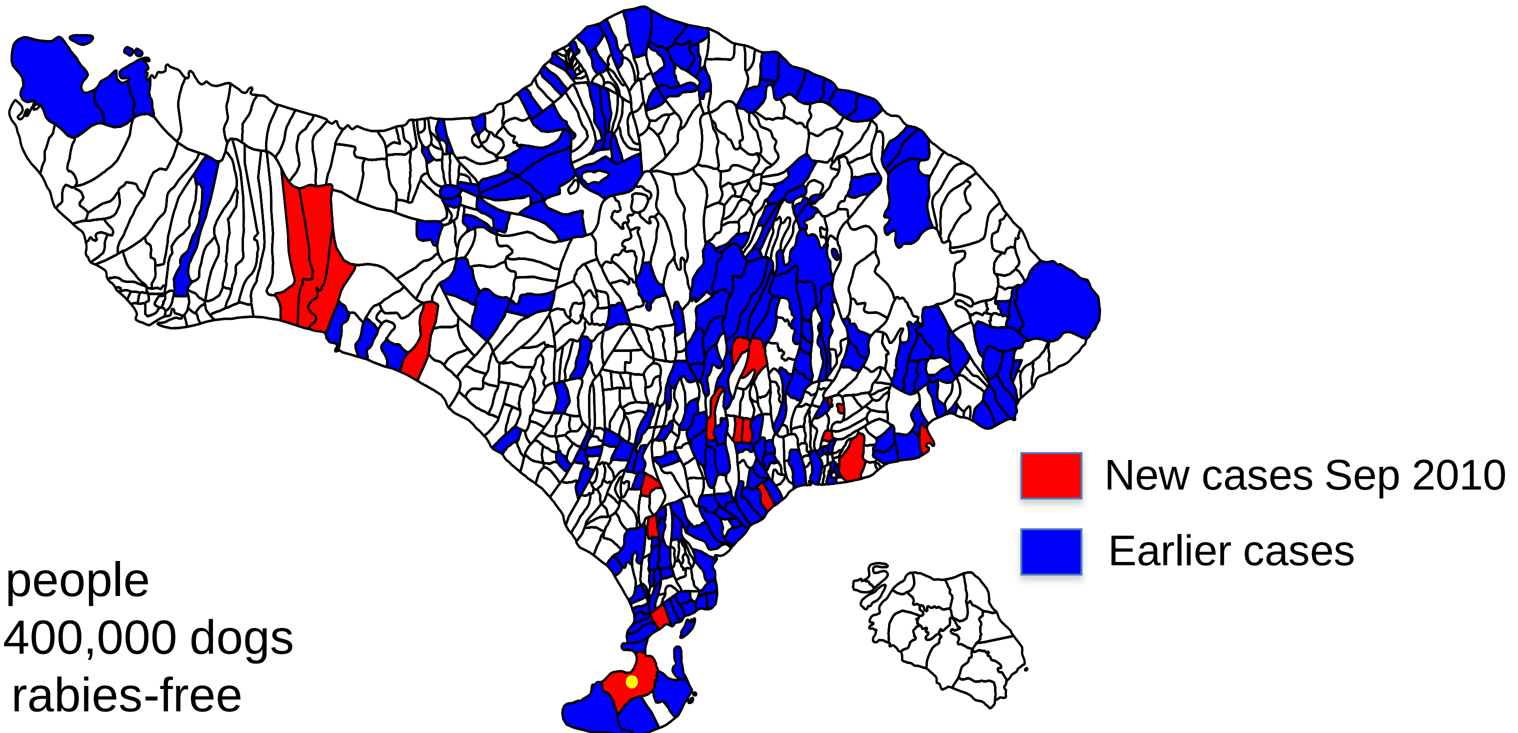
In more than 98% of cases the cause is a dog bite

In the developing world dogs are the primary reservoir

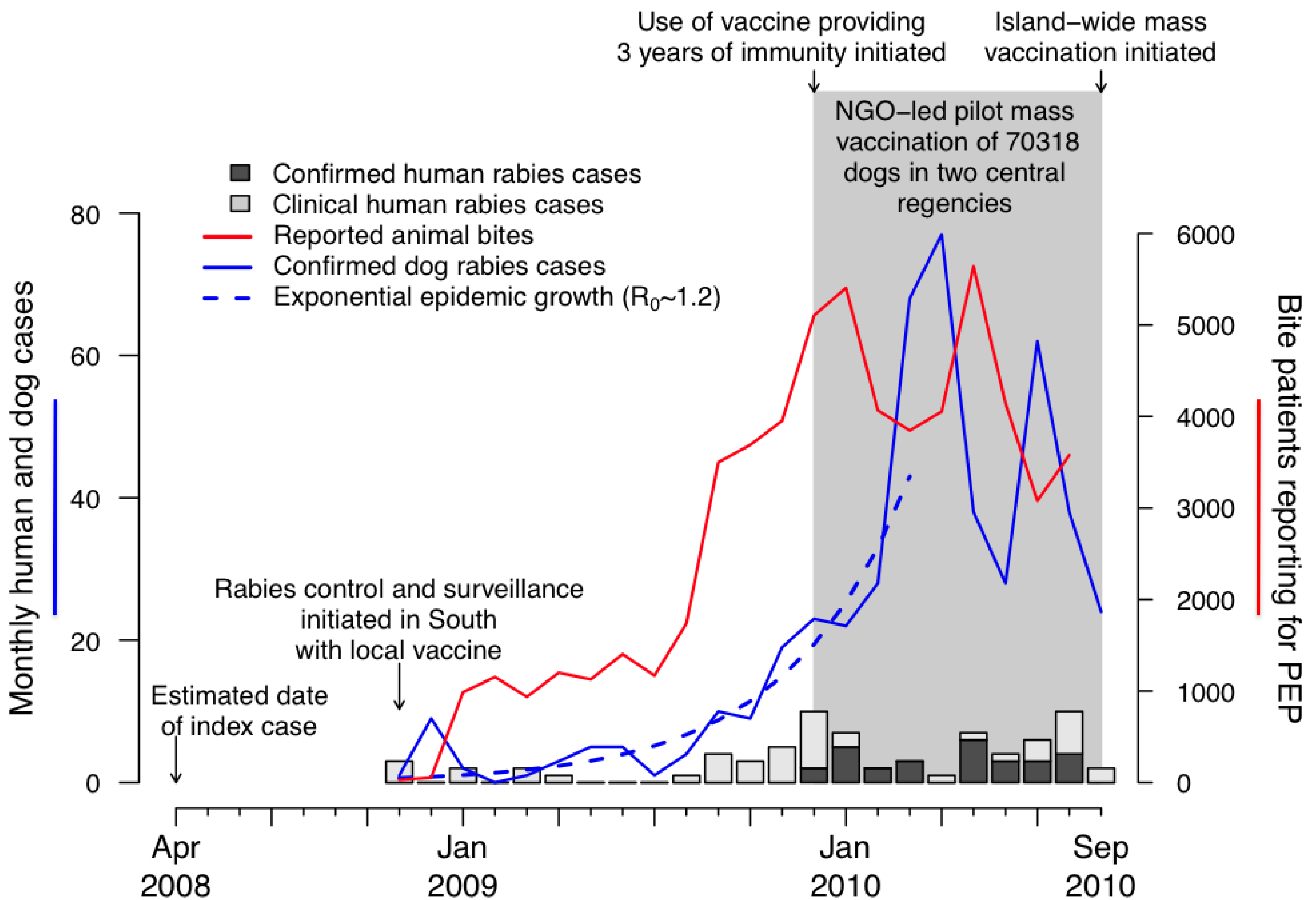
We have a cheap and effective vaccine

Bat-rabies is genetically distinct, and transmits poorly in other host species

Rabies in paradise



- 3.5 million people
- Estimated 400,000 dogs
- Previously rabies-free
- >100 human deaths since 2008
- Cases in all 9 regencies within ~2 years
- Early control attempts mostly through culling and low coverage vaccination
- Island-wide mass vaccination program started in September 2010



Use of vaccine providing
3 years of immunity initiated
Island–wide mass
vaccination initiated
NGO–led pilot mass
vaccination of 70318
dogs in two central
regencies
Confirmed human rabies cases
Clinical human rabies cases
Reported animal bites
Confirmed dog rabies cases
Exponential epidemic growth (R_0~1.2)
Monthly human and dog cases
Bite patients reporting for PEP
Rabies control and surveillance
initiated in South
with local vaccine
Estimated date
of index case
0
20
40
60
80
0
1000
2000
3000
4000
5000
6000
Apr
2008
Jan
2009
Jan
2010
Sep
2010

R_0

The number of secondary infections arising from the introduction of a single primary case in an otherwise entirely susceptible population

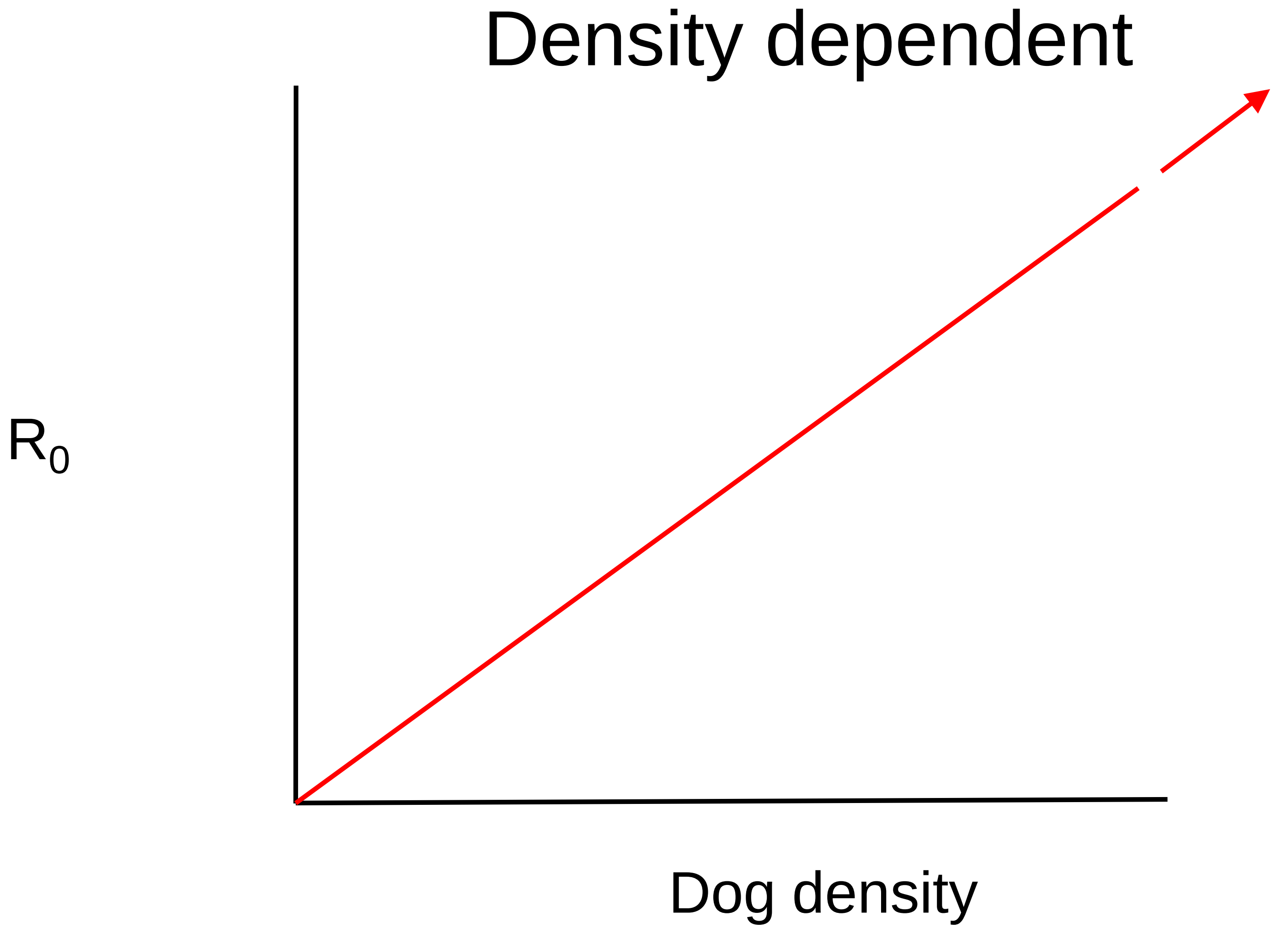
R_0 for rabies in domestic dogs

Table 2. Estimates of R_0 for Outbreaks of Rabies in Domestic Dog Populations around the World

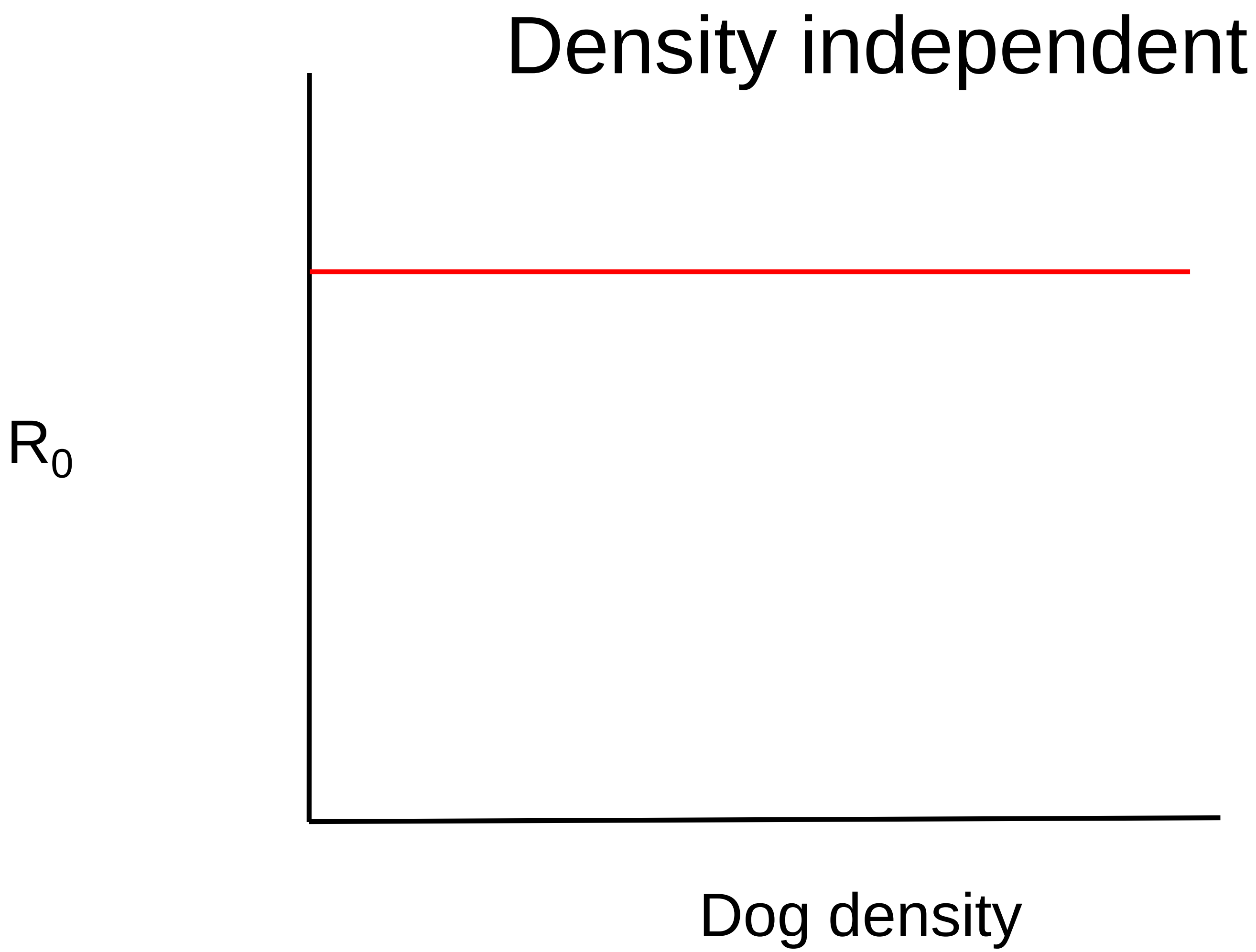
Site	R_0	95% Confidence Interval	Months (weeks)	Year	Setting
Tokyo, Japan [43]	1.05	1.04–1.06	29	1948	—
Kanagawa, Japan [44]	1.09	1.02–1.17	8	1917	—
Perak, Malaysia [45]	1.12	0.99–1.27	6	1951	Rural
Israel [46]	1.12	1.07–1.19	9	1948	—
Ngorongoro District, Tanzania (Figure 3B)	1.14 (1.10)	0.94–1.32 (0.98–1.23)	13 (52)	2003	Rural
Serengeti District, Tanzania (Figure 3B)	1.19 (1.18)	1.12–1.41 (1.08–1.29)	11 (44)	2003	Rural
Lima-Callau, Peru [47]	1.19	1.03–1.38	8	1984	Urban
Tokyo, Japan [44]	1.25	1.14–1.37	4	1918	Urban
Hong Kong [48]	1.27	1.02–1.60	8	1949	Urban
Central New York, USA [49]	1.32	1.25–1.40	11	1944	Rural
Central Java, Indonesia [50]	1.49 (1.63)	1.23–1.80 (1.32–2.02)	4 (15)	1985	Rural
Selangor, Malaysia [45]	1.62	1.48–1.82	11	1951	Urban
Hermosillo, Mexico [28]	1.68	1.52–1.91	11	1987	Urban
Memphis, USA (<10% coverage) [51]	1.69 (1.80)	1.33–2.17 (1.44–2.23)	3 (11)	1947	Urban and Rural
Sultan Hamad, Kenya (~24% coverage) [52]	1.72 (1.85)	1.34–2.18 (1.03–2.92)	4 (14)	1992	Rural

Hampson et al. Transmission Dynamics and Prospects for the Elimination of Canine Rabies. (2009). *PLoS Biology* Vol. 7, No. 3, e53.

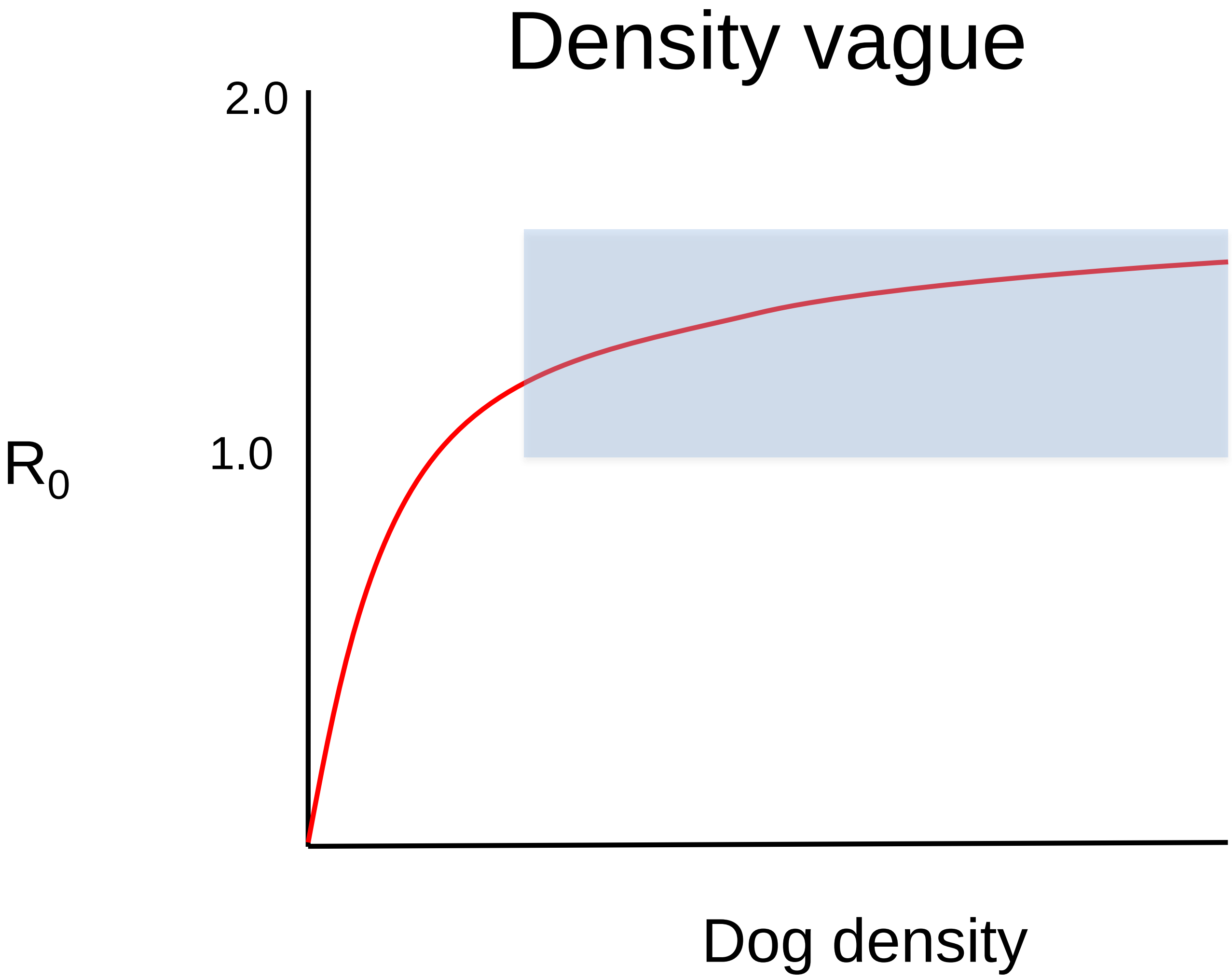
The relationship between density and R_0



The relationship between density and R_0



The relationship between density and R_0



What did we want to know?

Does it matter exactly how we roll-out island-wide vaccination?

How much does it matter that dogs move?

How do elimination prospects depend on % coverage?

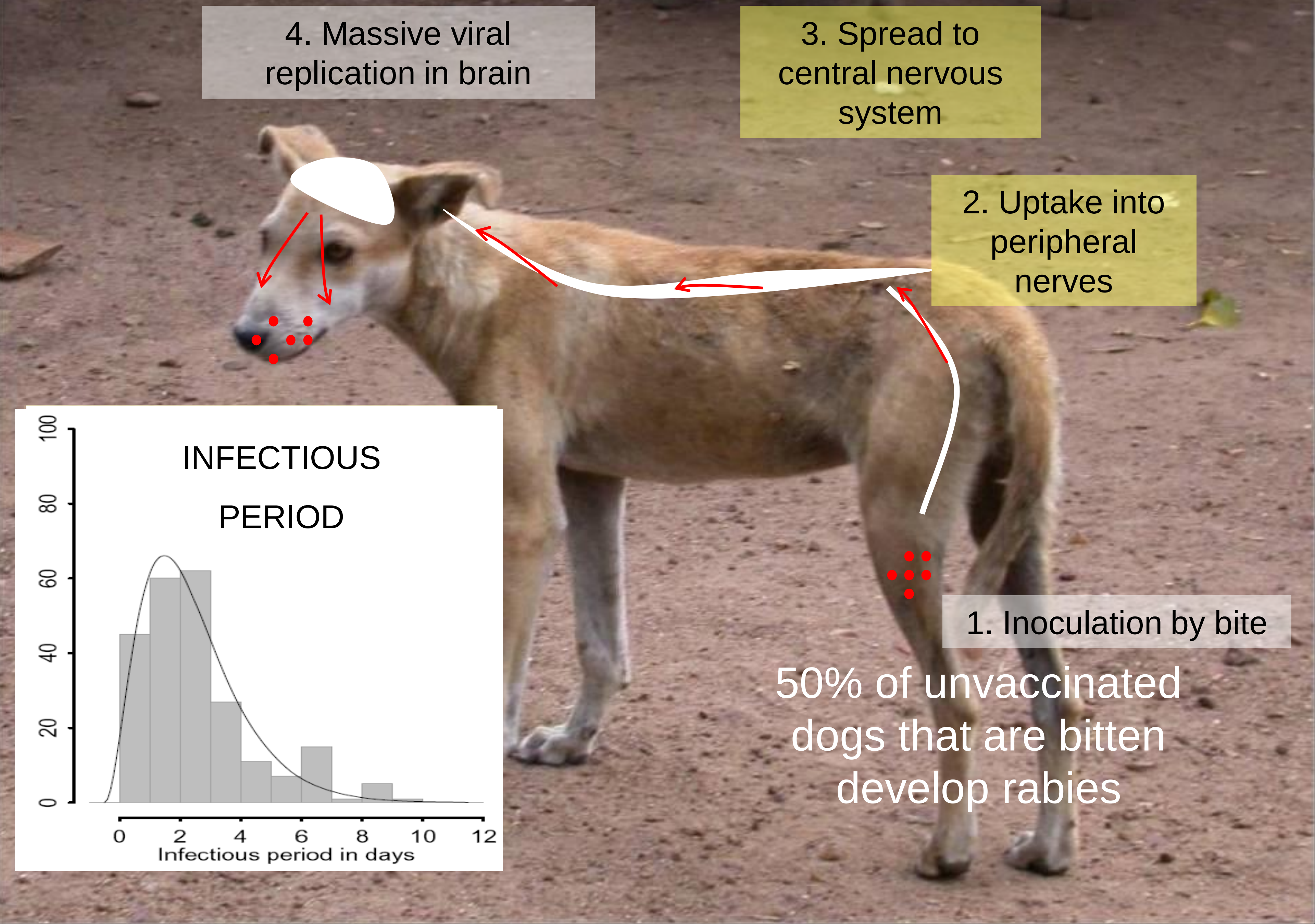
How do elimination prospects depend on R_0?

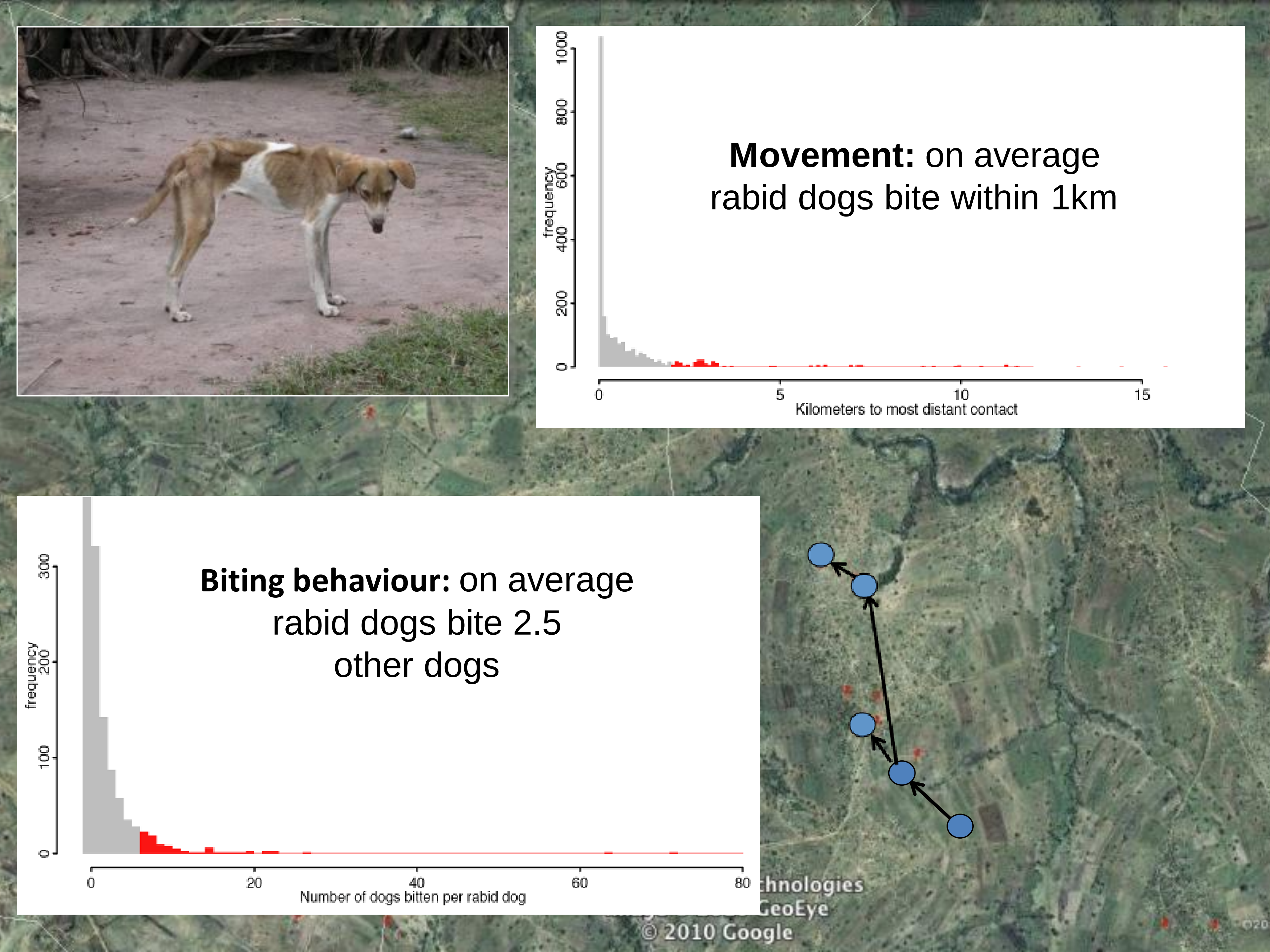
How sensitive are elimination prospects to ‘holes in the coverage’?

What is the role of dog ‘demographic turnover’?

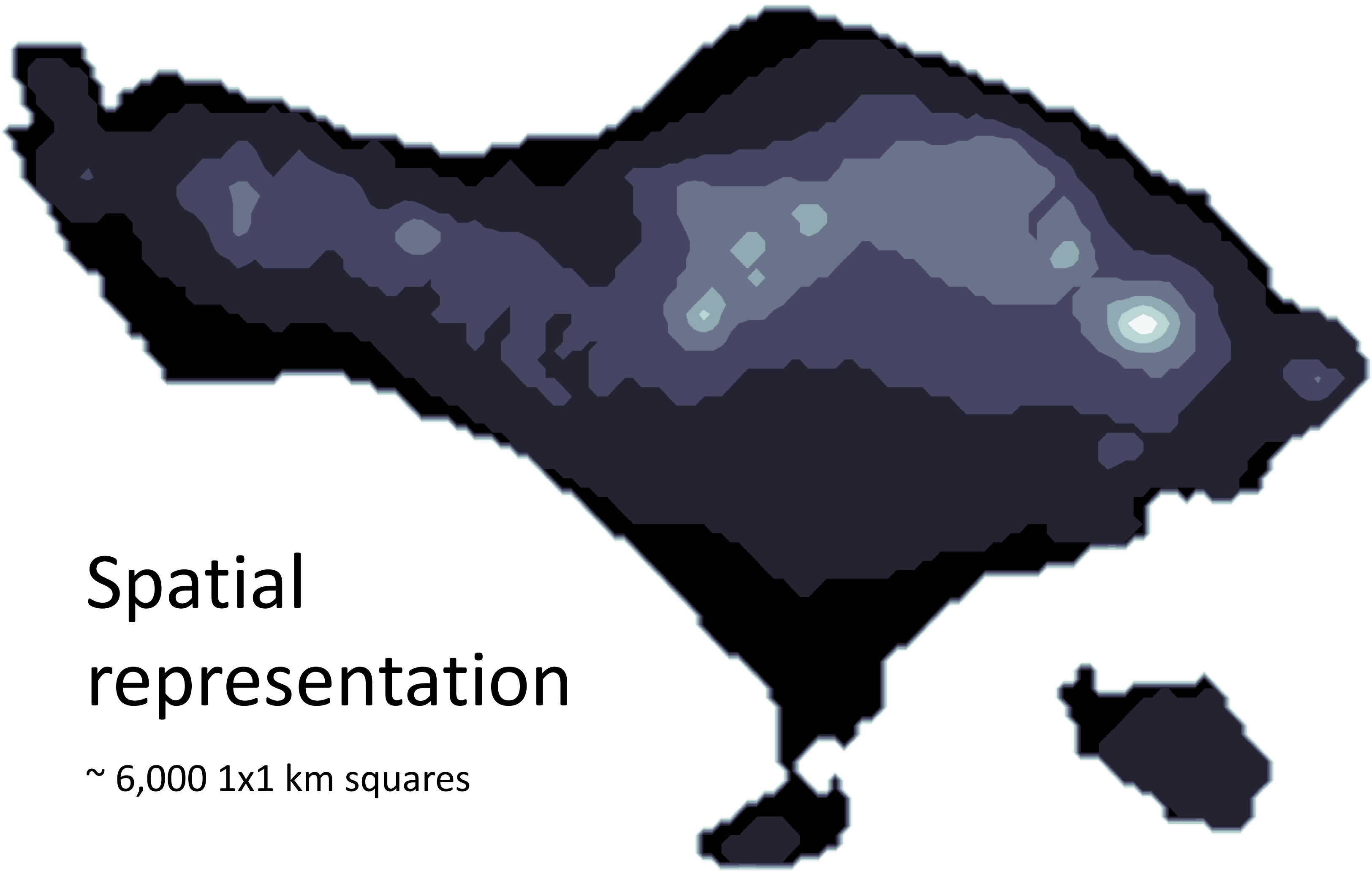
And the role of the duration of immunity?

Transmission model based on rabies epidemiology




Movement: on average rabid dogs bite within 1km
frequency
0
200
400
600
800
1000
0
5
10
15
Kilometers to most distant contact
Biting behaviour: on average rabid dogs bite 2.5 other dogs
frequency
0
100
200
300
0
20
40
60
80
Number of dogs bitten per rabid dog
© 2010 Google

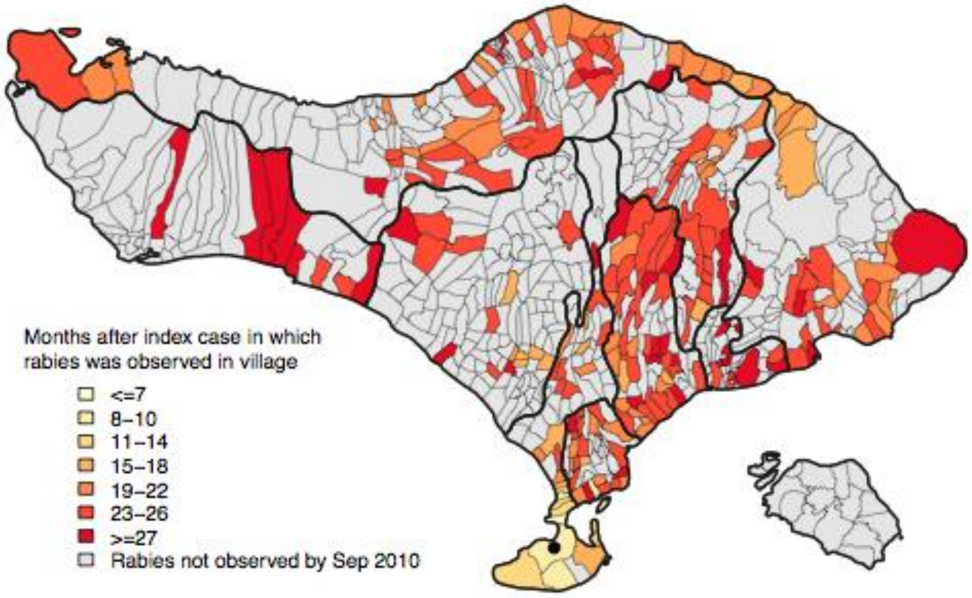
How dog movement is modelled:



Spatial representation

~ 6,000 1x1 km squares

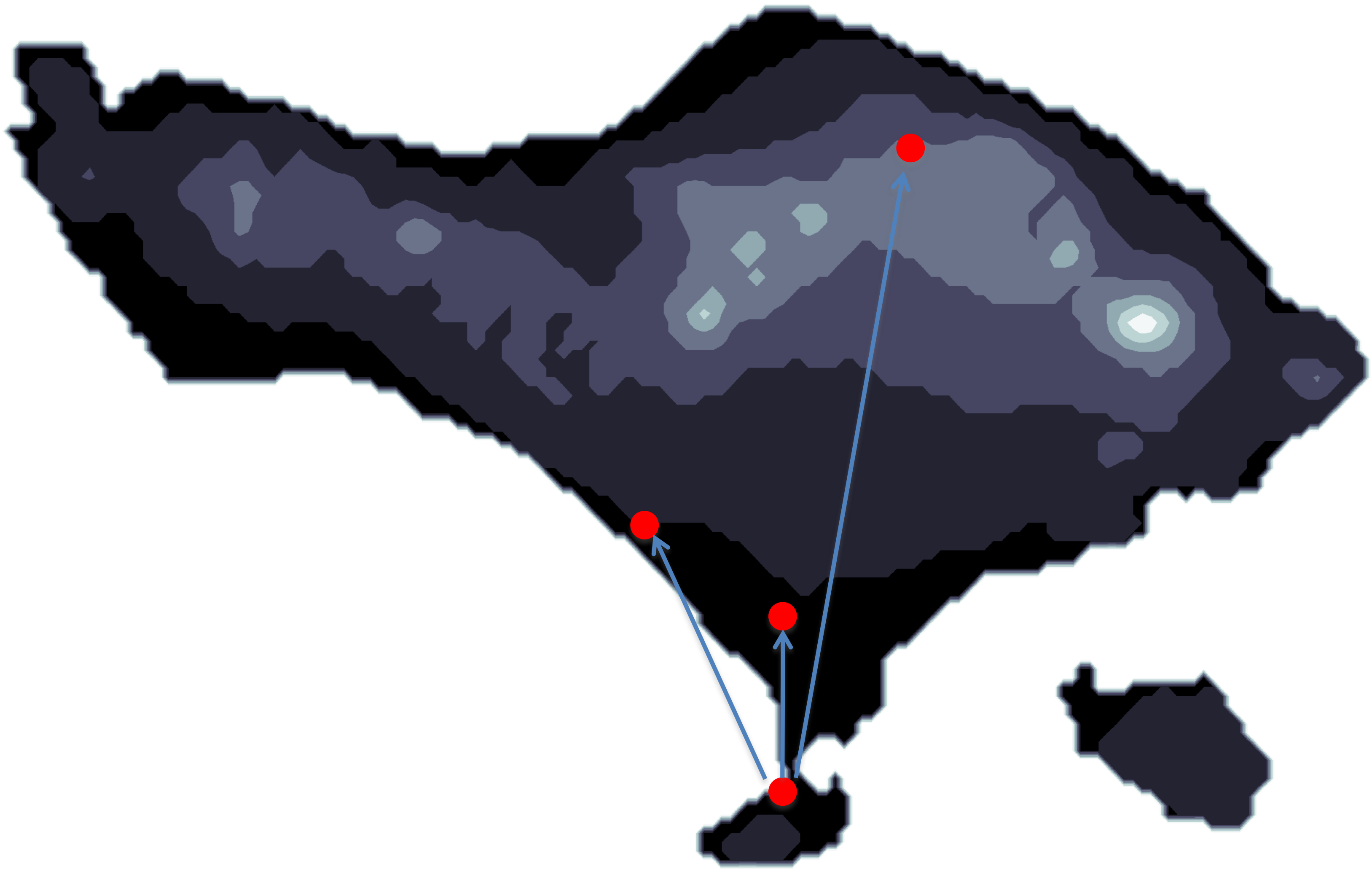
How dog movement is modelled:

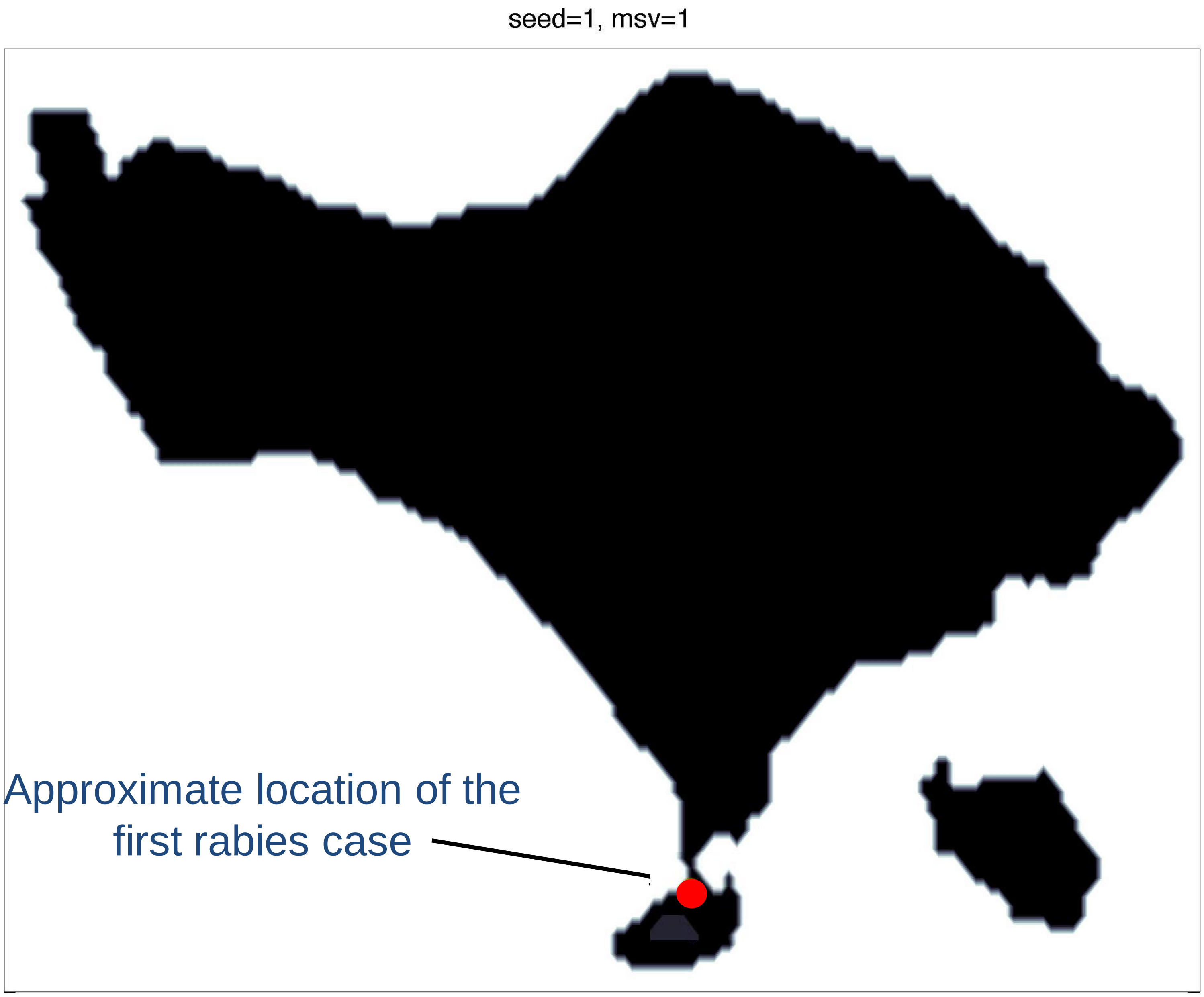


95% of transmission is local

5% of incubating dogs transported long distance

How dog movement is modelled:





Modelled vaccination coverage and rabies cases

seed=1, msv=2

seed=1, msv=3

seed=1, msv=4

seed=1, msv=5

seed=1, msv=6

seed=1, msv=7

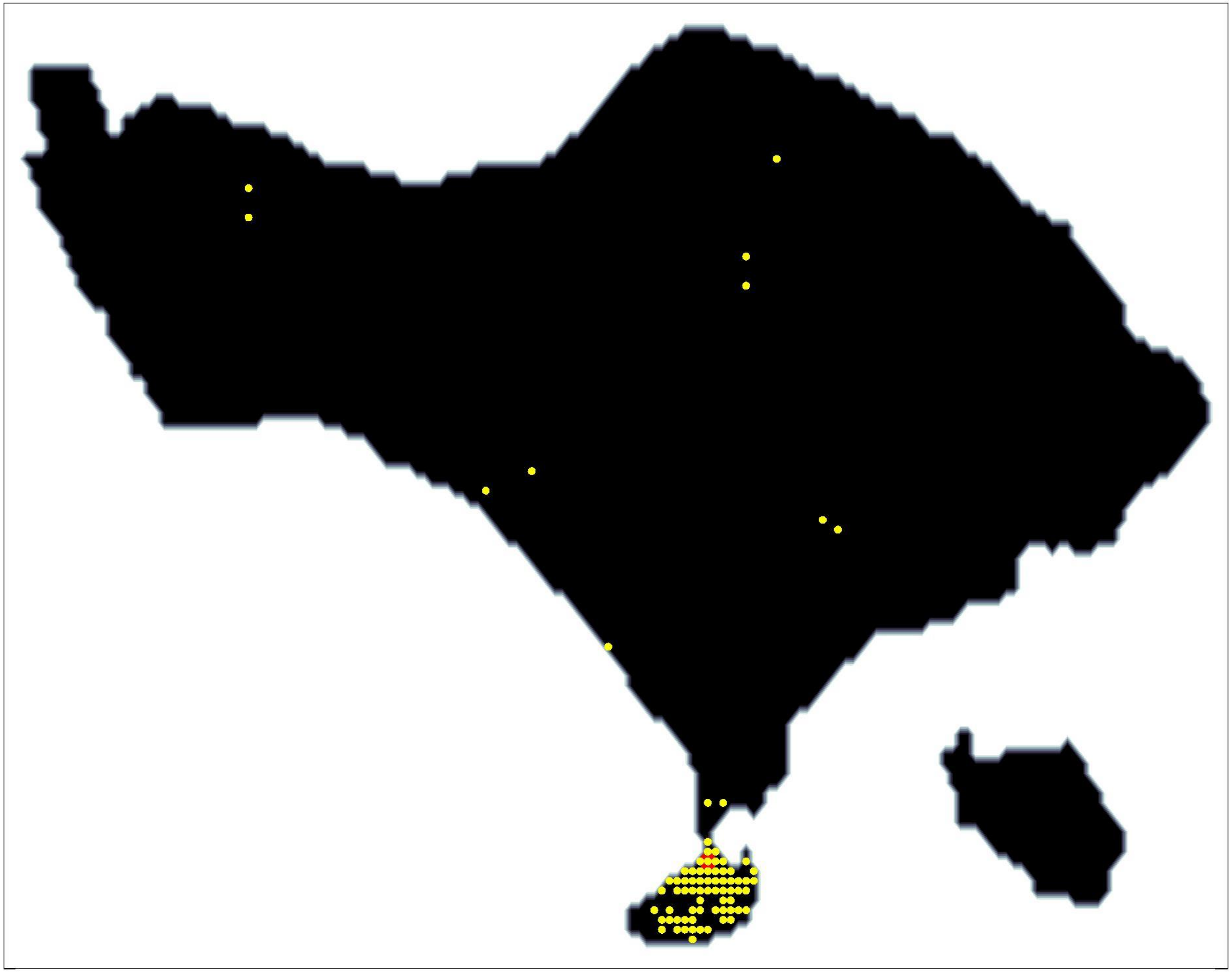
seed=1, msv=8

seed=1, msv=9

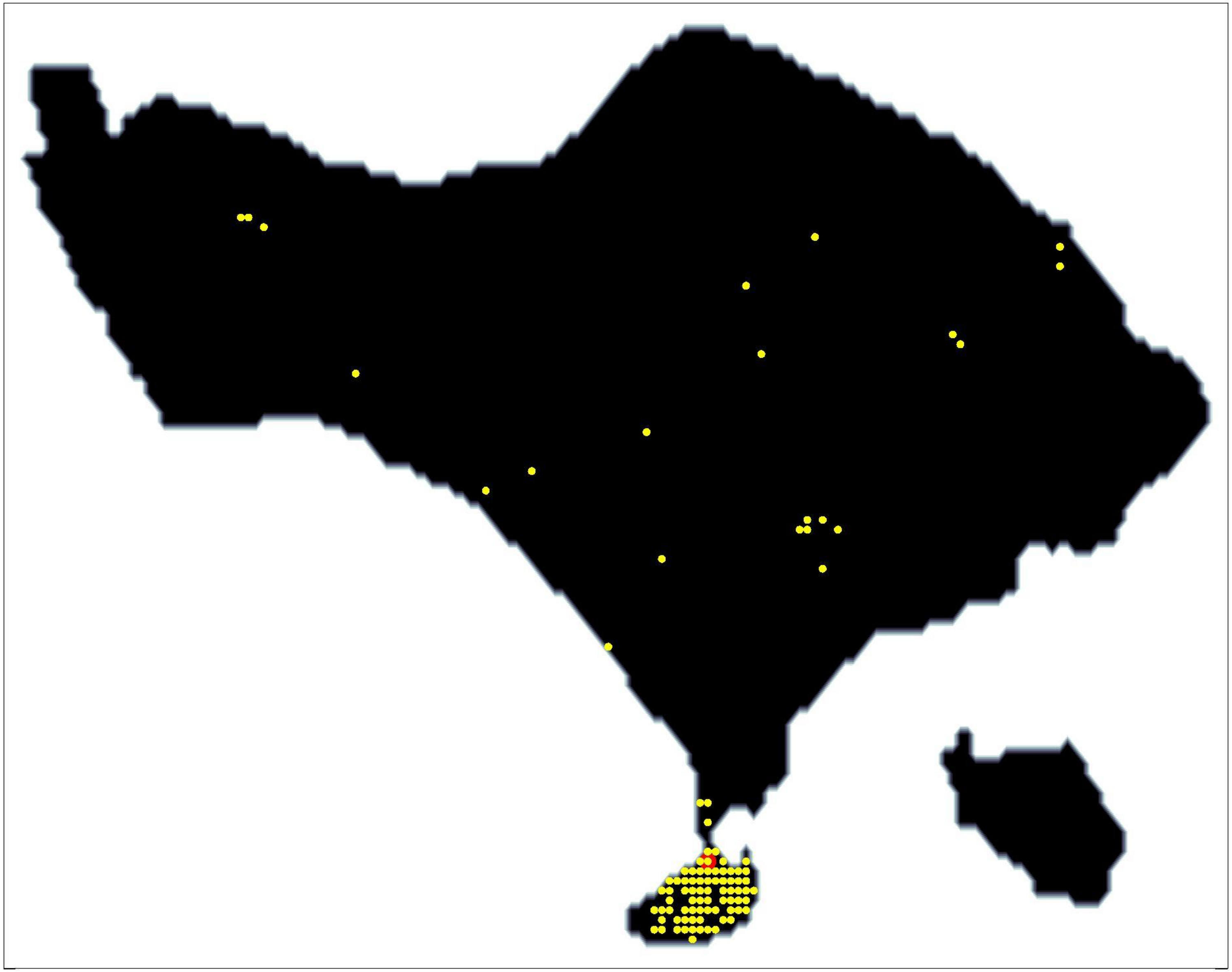
seed=1, msv=10

seed=1, msv=11

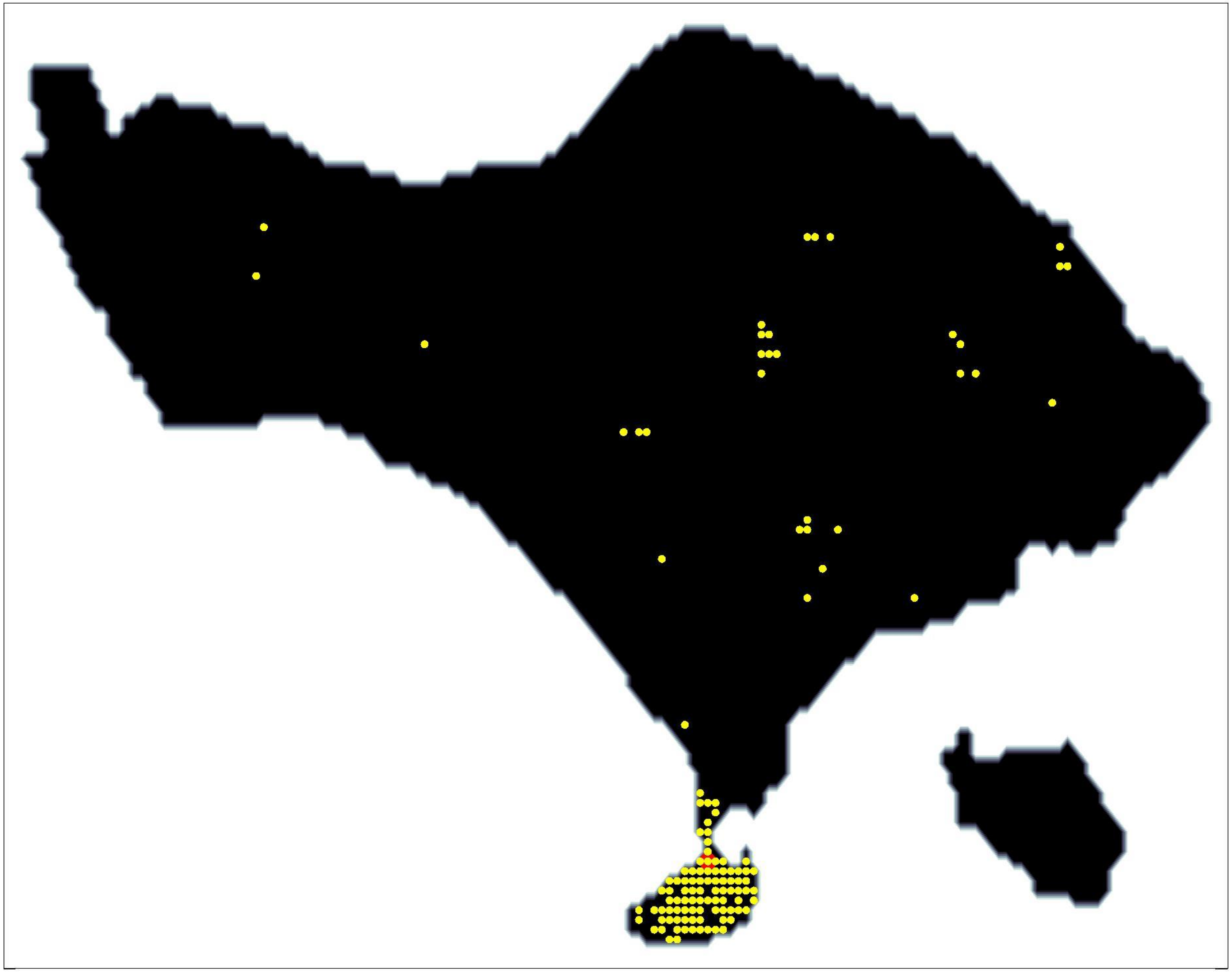
seed=1, msv=12



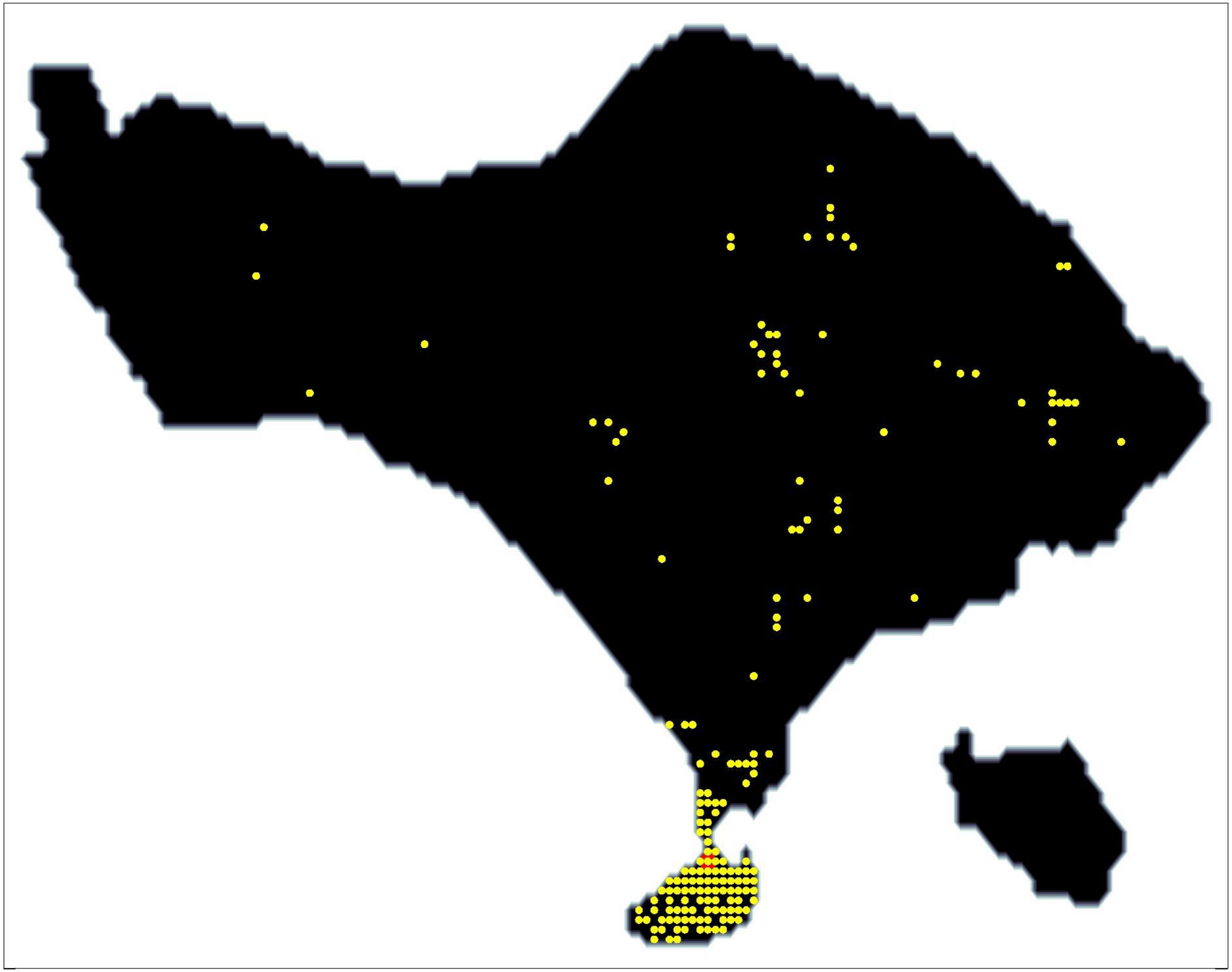
seed=1, msv=13



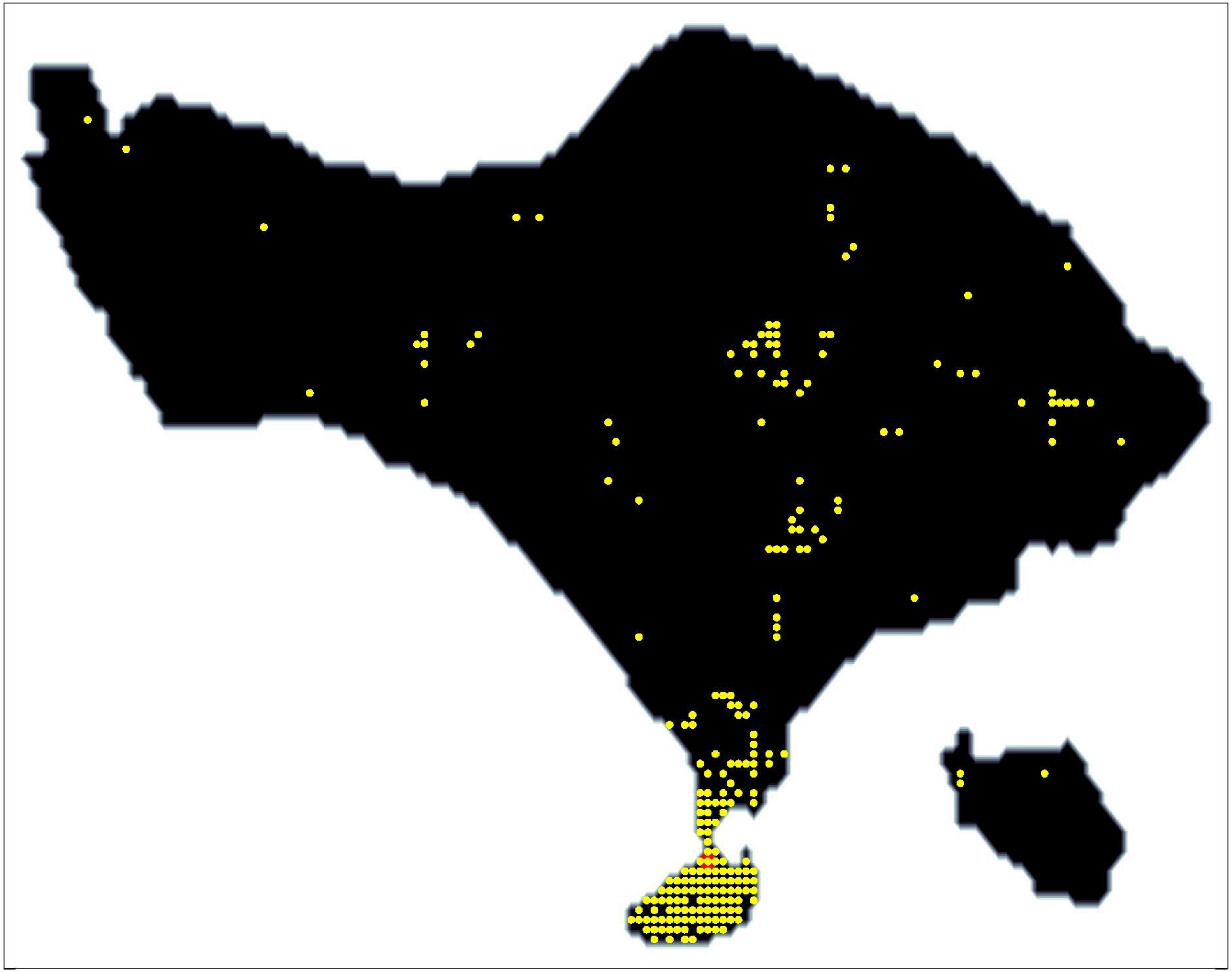
seed=1, msv=14



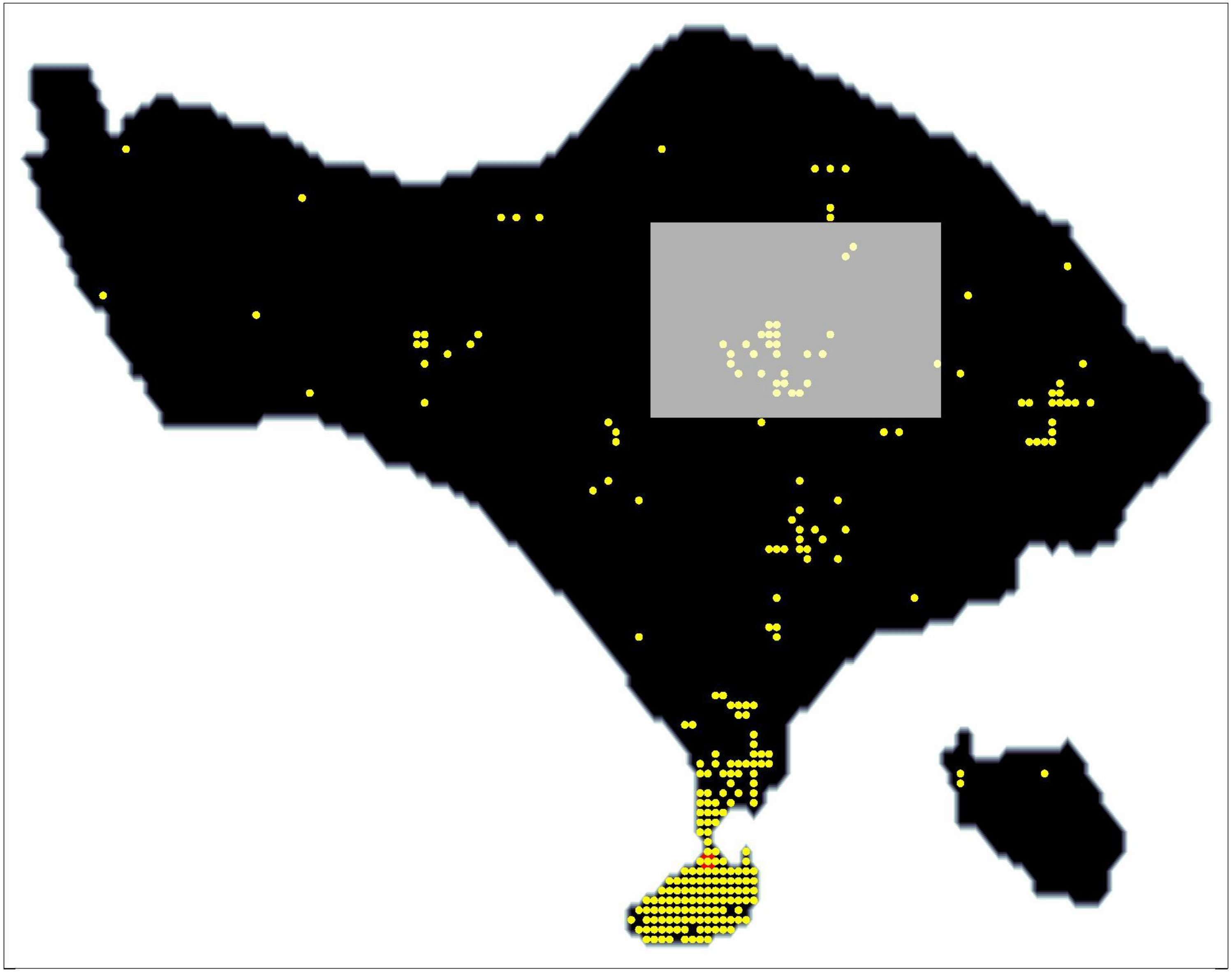
seed=1, msv=15



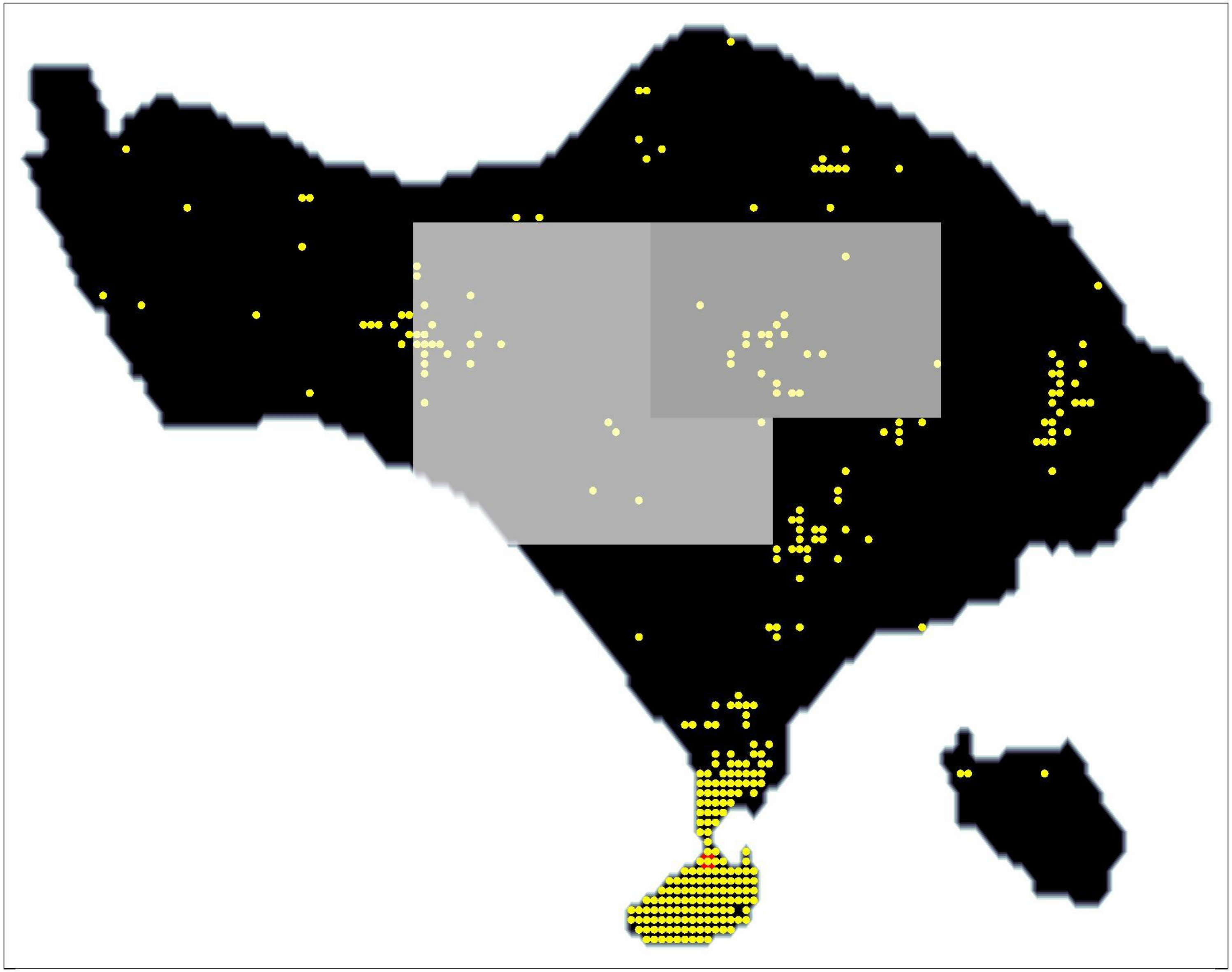
seed=1, msv=16



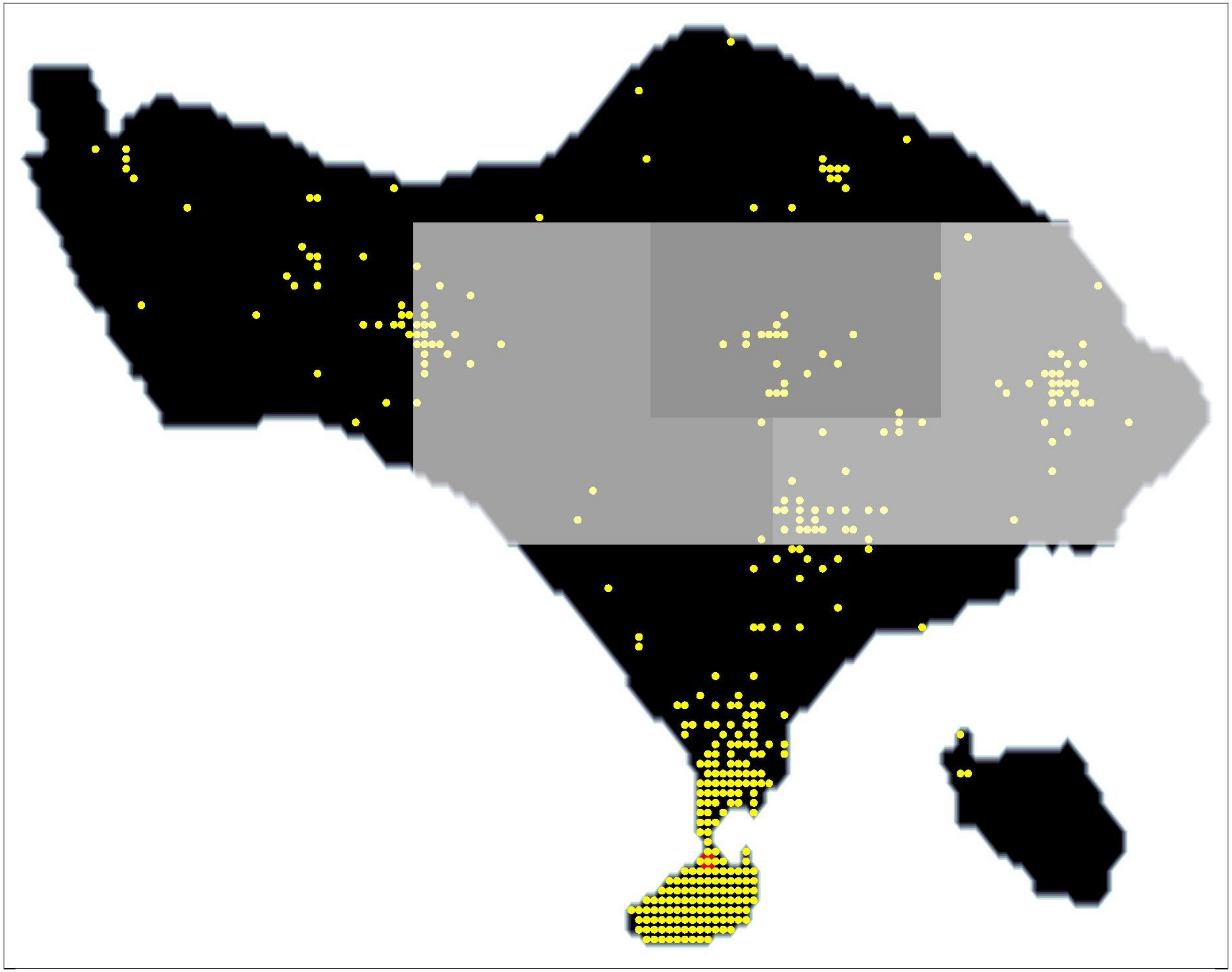
seed=1, msv=17



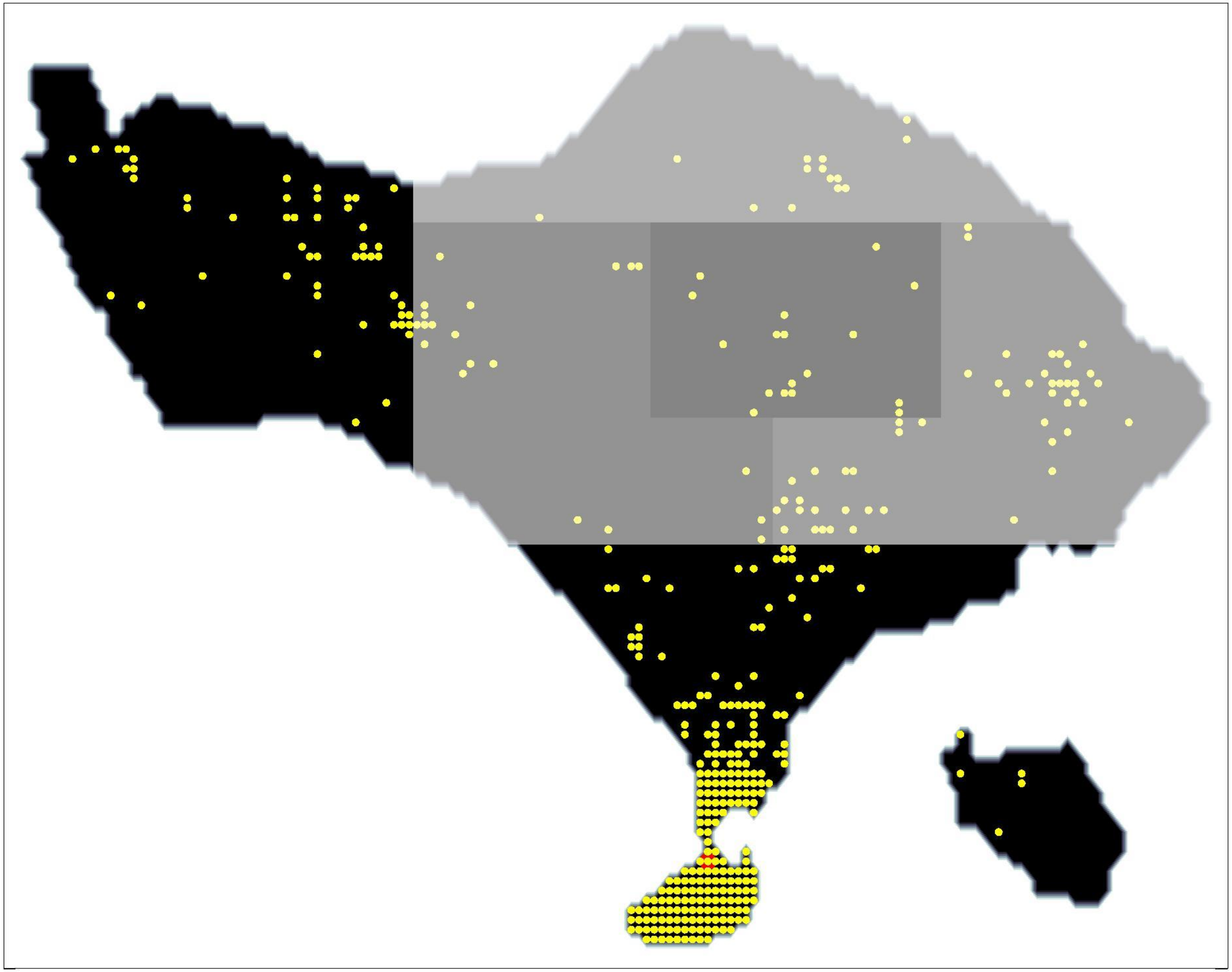
seed=1, msv=18



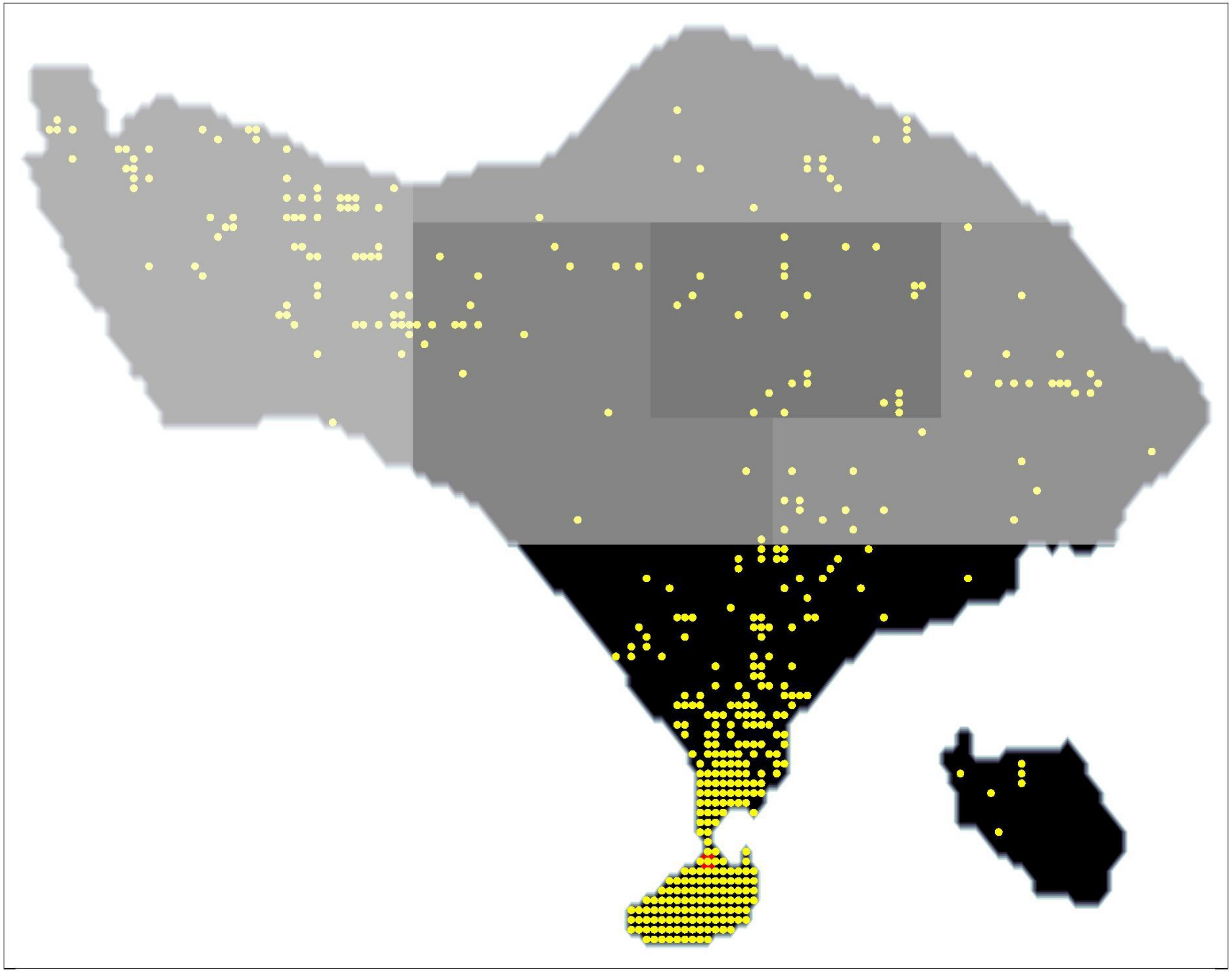
seed=1, msv=19



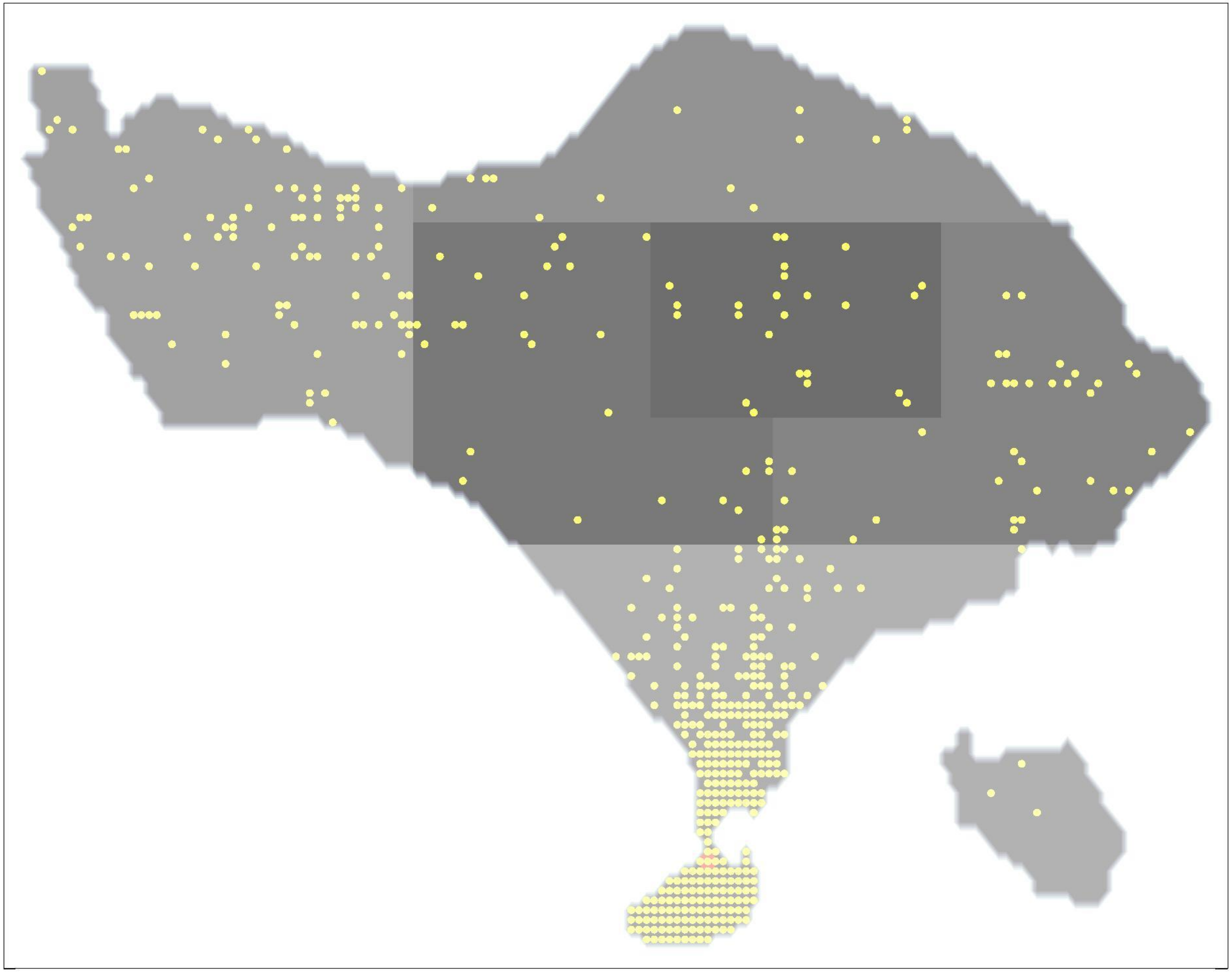
seed=1, msv=20



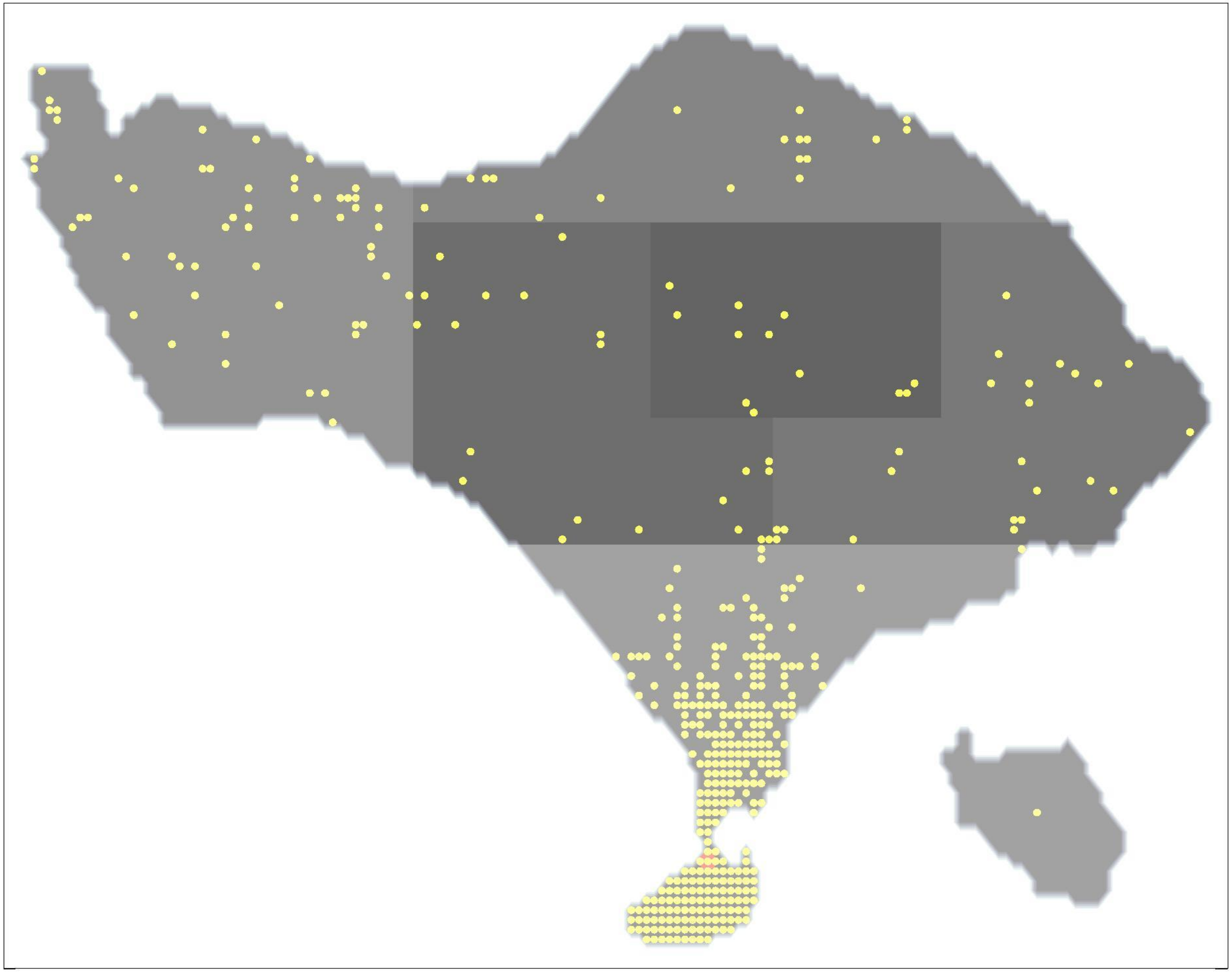
seed=1, msv=21



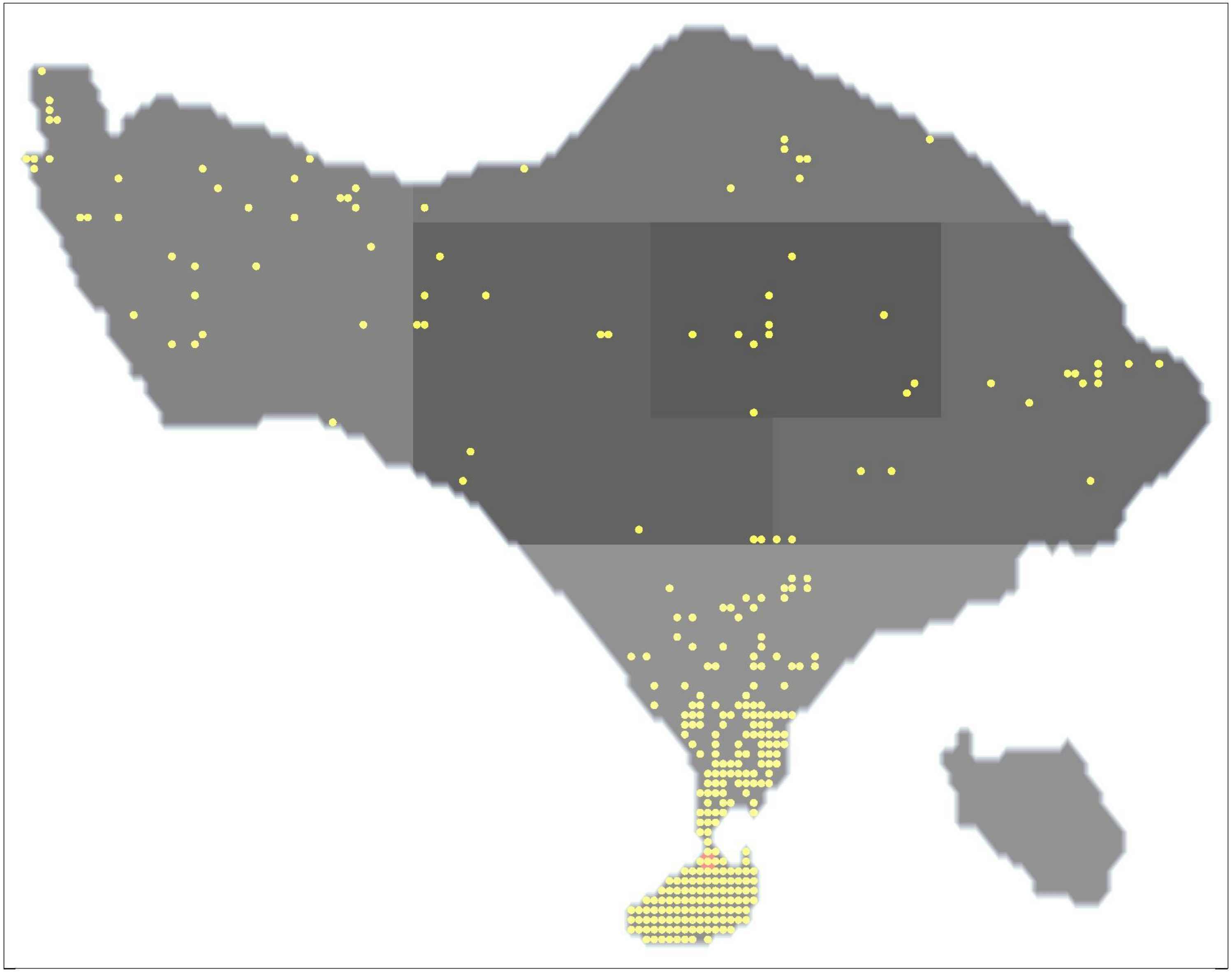
seed=1, msv=22



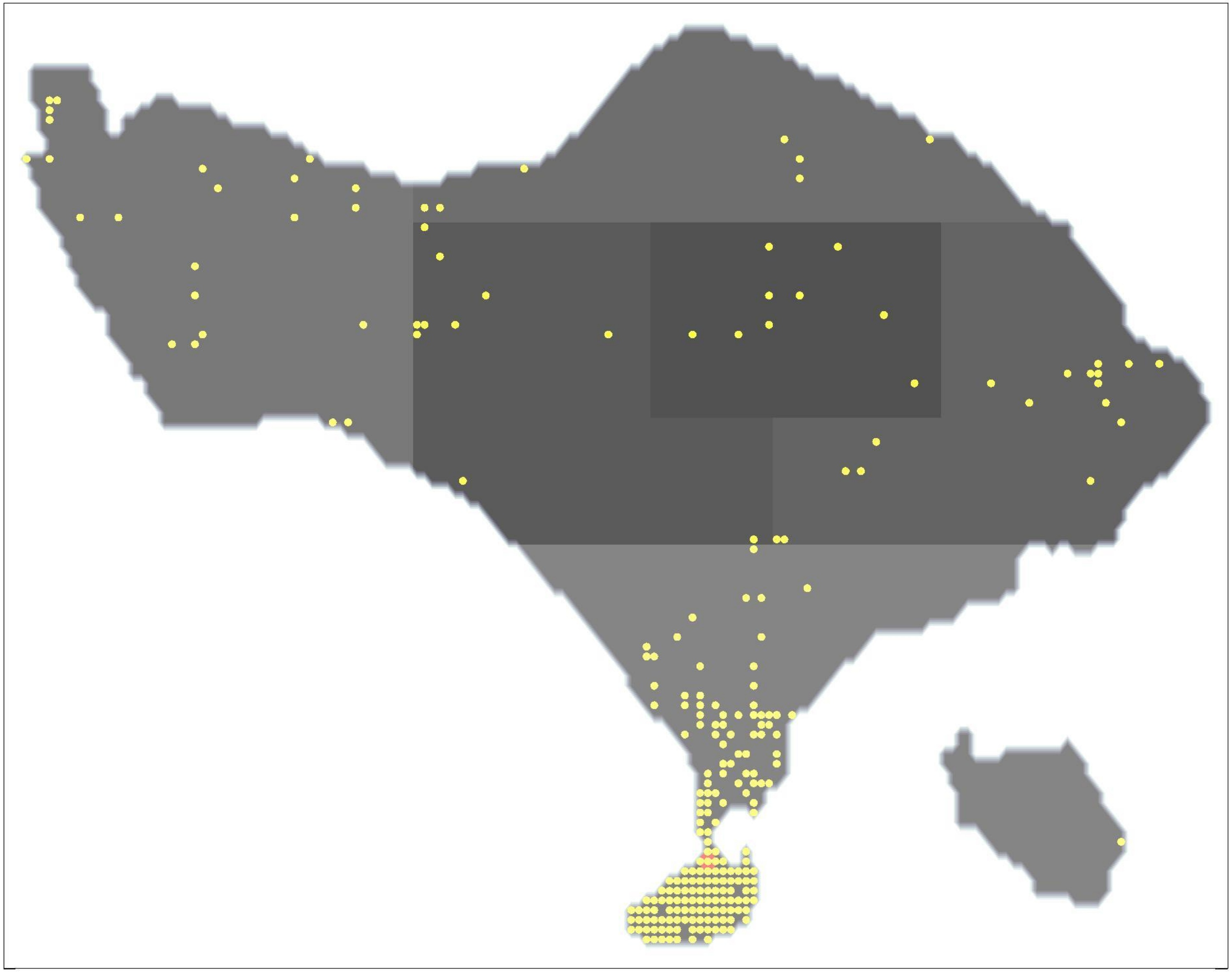
seed=1, msv=23



seed=1, msv=24



seed=1, msv=25



seed=1, msv=26

seed=1, msv=27

seed=1, msv=28

seed=1, msv=29

seed=1, msv=30

seed=1, msv=31

seed=1, msv=32

seed=1, msv=33

seed=1, msv=34

seed=1, msv=35

seed=1, msv=36

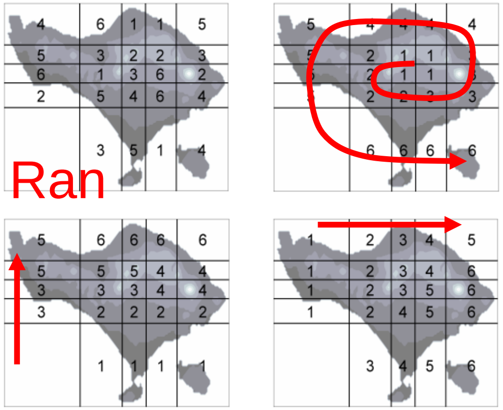
seed=1, msv=37

seed=1, msv=38

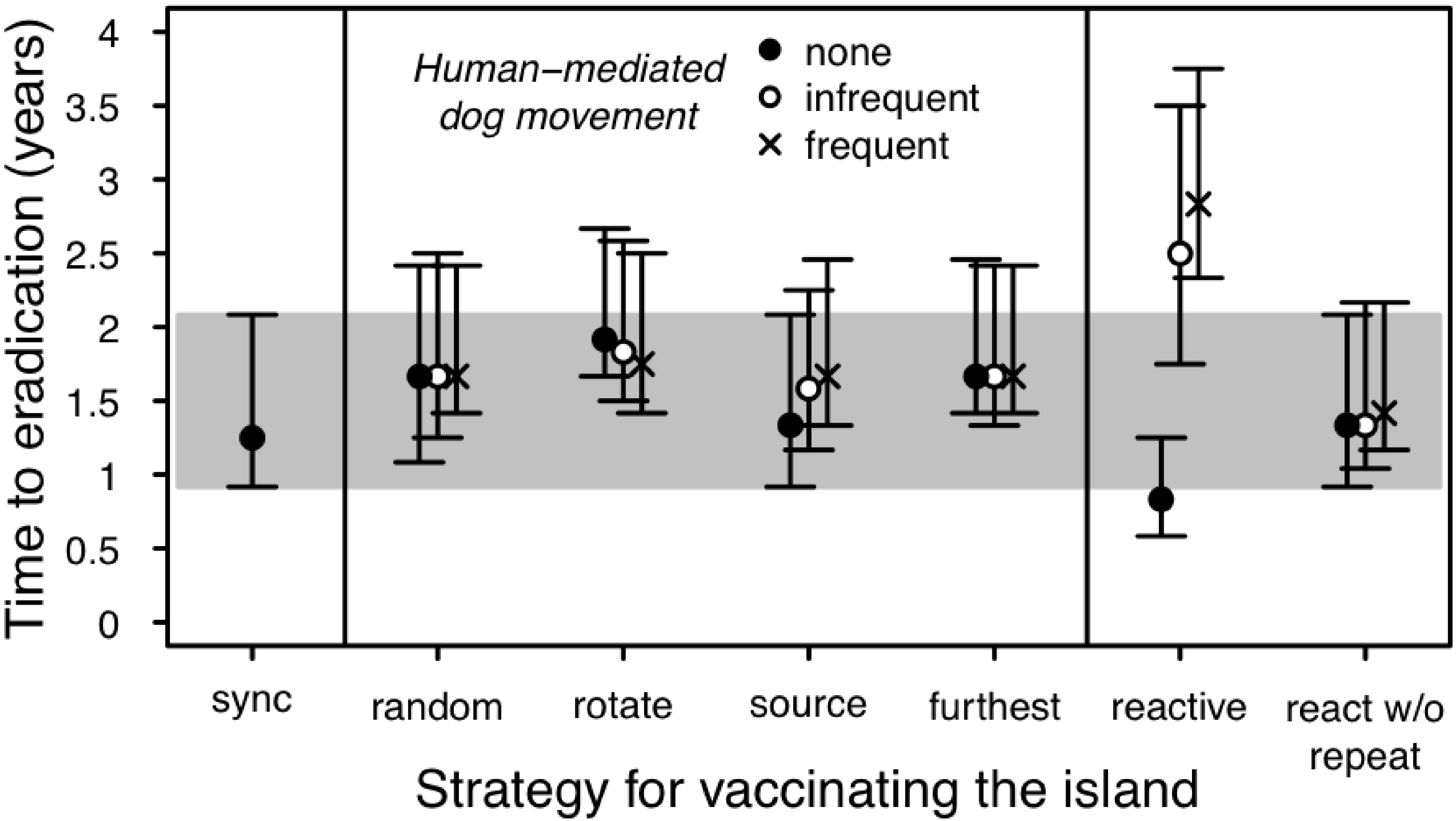
seed=1, msv=39

Does it matter exactly how we roll-out island-wide vaccination?

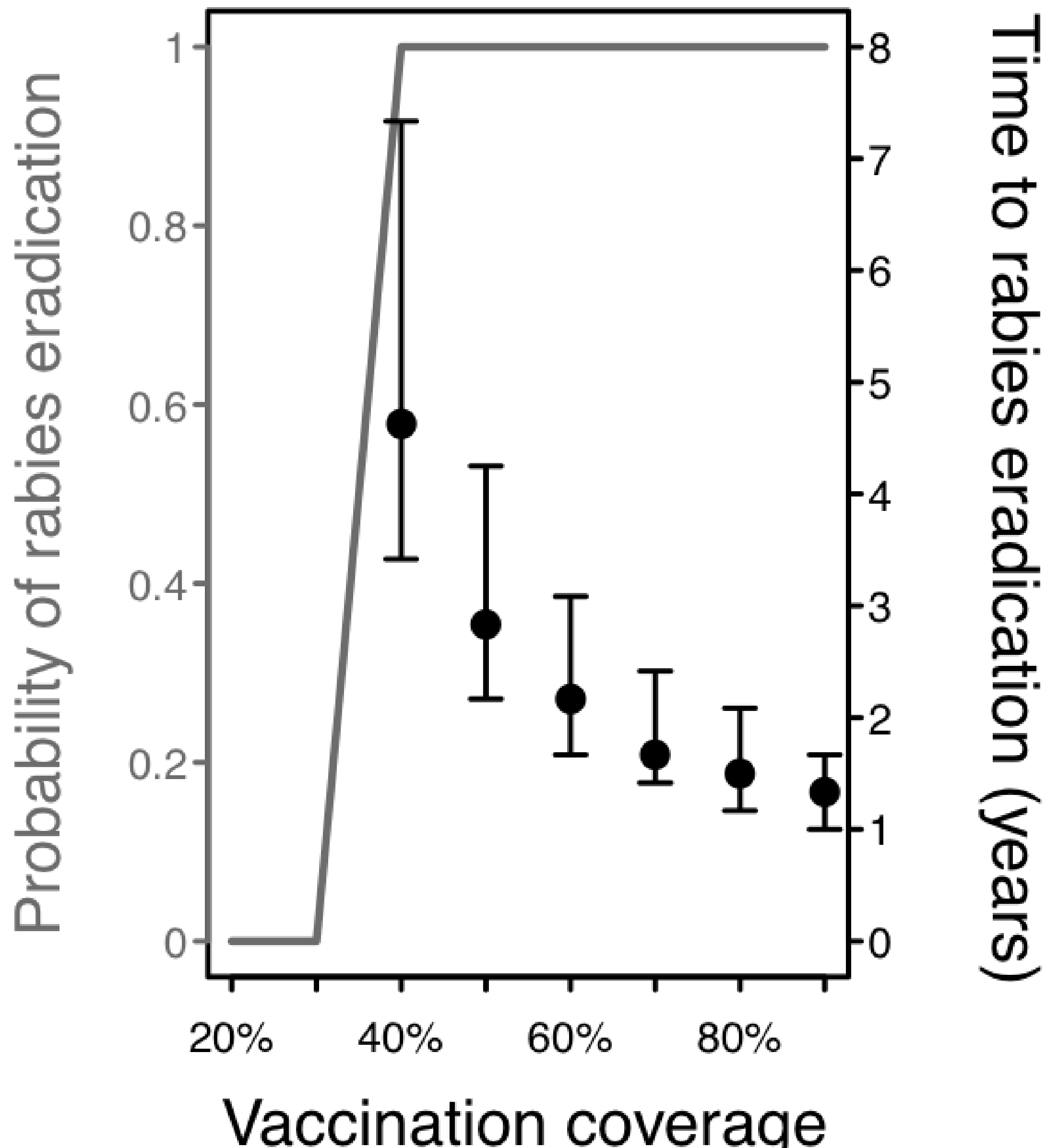
A Synchronous: vaccination of the island in one month
B Random: ordering of blocks, completed in 6 months
C Rotate: start in the centre and rotate anticlockwise
D Source: start close to the index case and spread north
E Furthest: start in the north and spread south
F Reactive: prioritize blocks with the highest number of cases the month before
G React w/o repeat: as for F but don't choose the same block twice in a campaign
H Actual (Nov 2008 – Dec 2011)



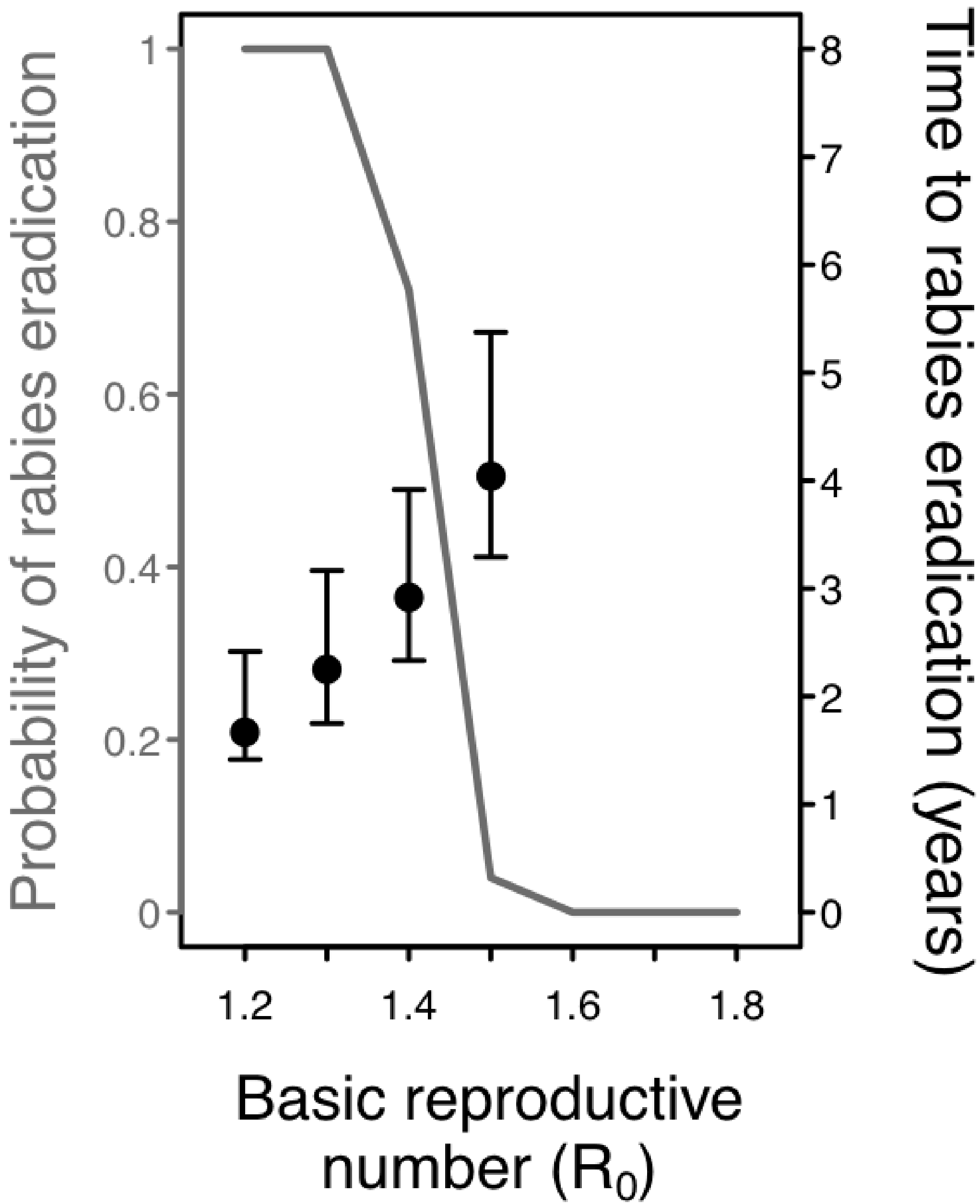
Assuming 70% coverage for each annual campaign and no gaps ..



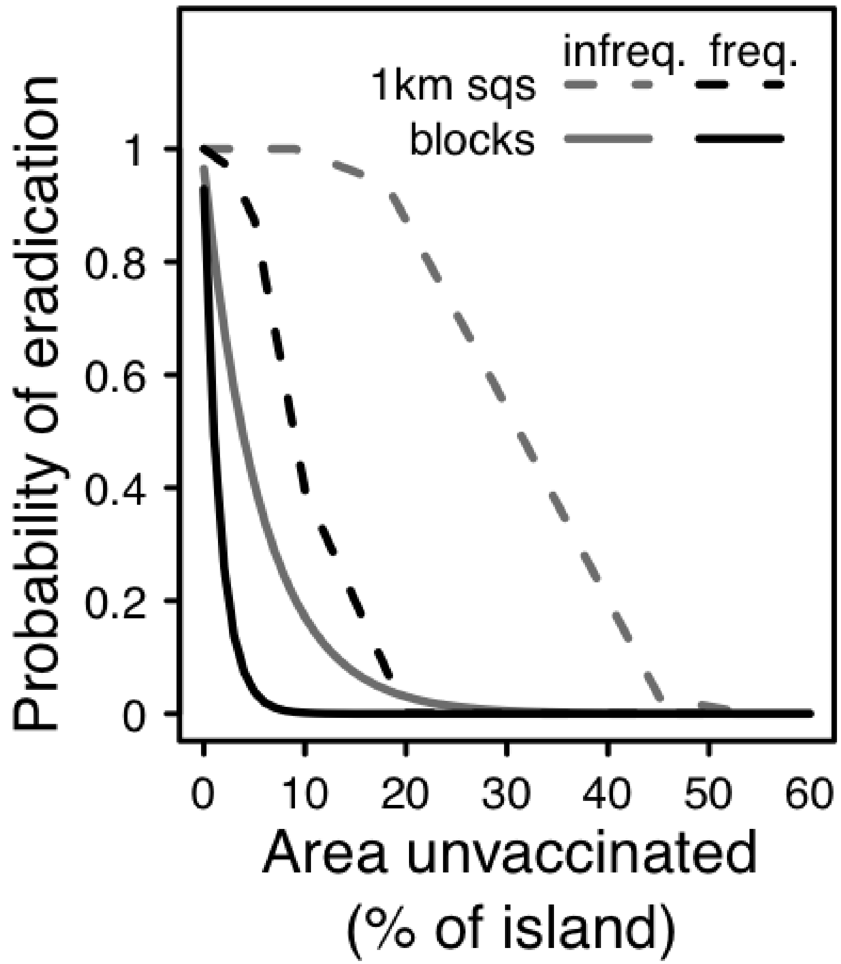
How do elimination prospects depend on % coverage?



How do elimination prospects depend on R_0?

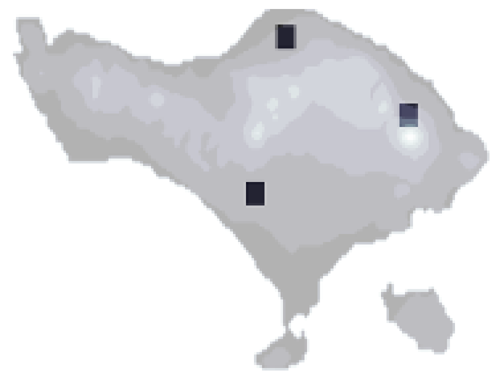


How sensitive are elimination prospects to 'holes' in the coverage?



… so unvaccinated villages could jeopardize elimination

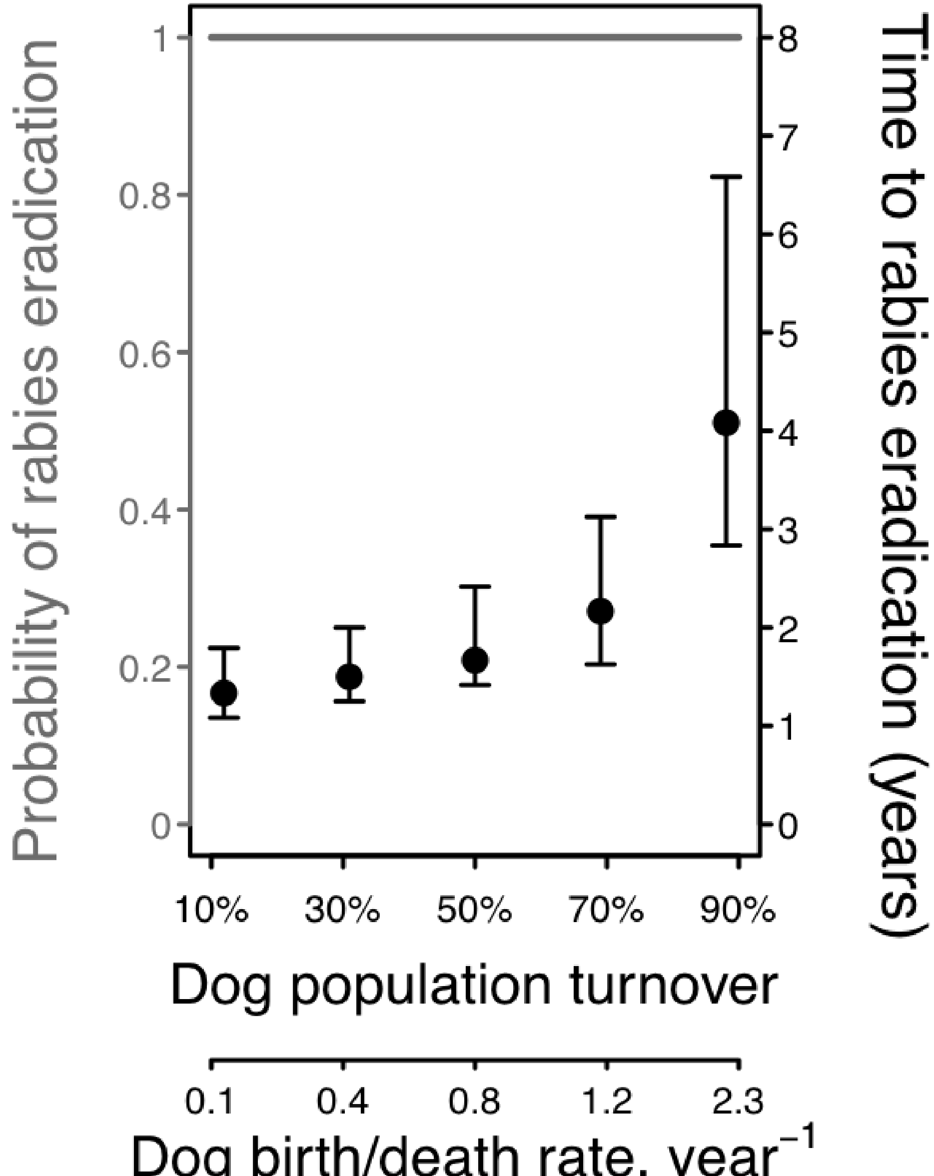
Reached all villages
100% success ☺



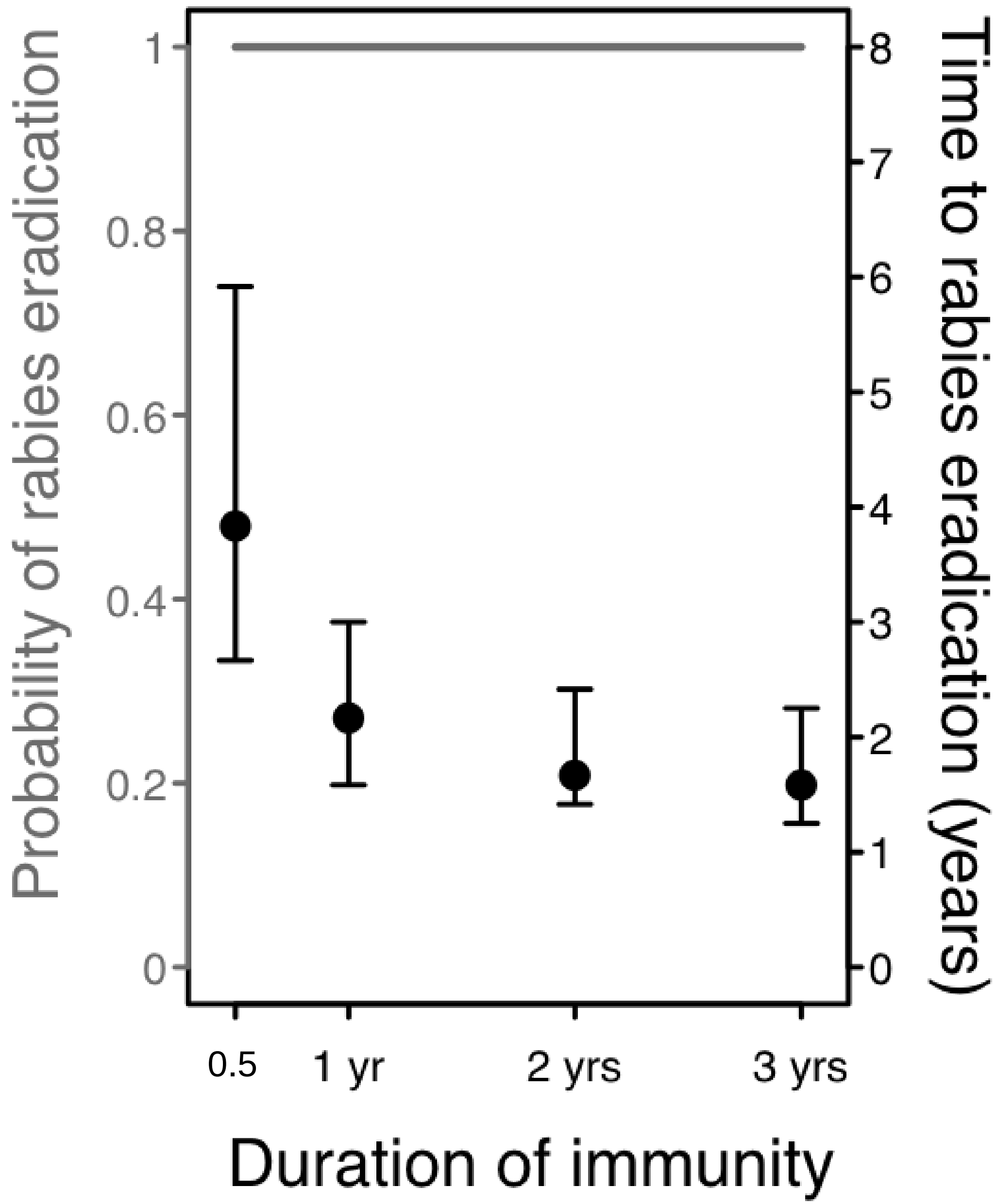
3 villages missing
99% success

3 clustered villages missing:
<90% success ☹

What is the role of dog ‘demographic turnover?



And the role of the duration of immunity?



Conclusion

Consistently high coverage is more important than anything else

Consistently high regional compliance is critical

Culling is likely to be counter-productive

Political commitment is essential, especially in the end-game