HOW DO IMMUNE AND SPATIAL MECHANISMS IMPACT PATHOGEN PERSISTENCE IN BATS?

Leveraging GPS telemetry within parameterized models of henipavirus infection dynamics in the endemic Malagasy fruit bat, *Eidolon dupreanum*

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BACKGROUND

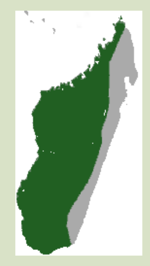
How do pathogens persist?

Bats have several **unique traits** that may influence pathogen persistence, including:

- fission-fusion population structures
- roosting aggregations
- seasonal birth pulses
- maternal colonies
- immune system adaptations
- migration

We seek to combine hypothesized mechanistic SIR models with novel bat movement data to explore the relative importance of these mechanisms.

STUDY SYSTEM



Species: *Eidolon dupreanum*
Roost Type: Caves, dense palms
Location: Madagascar, endemic
Conservation Status: Vulnerable
Reservoir Status: known to host potentially zoonotic pathogens including coronaviruses, henipaviruses, etc.

IMMUNE MECHANISMS

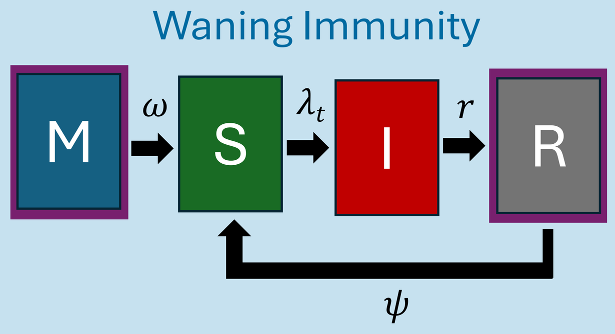
We built three **stochastic, age-structured Leslie matrix metapopulation models** which include different putative immune mechanisms. By simulating infection dynamics using these three models, we can determine how the inclusion of different immune mechanisms influences persistence.

Additional model features

- Discrete, biweekly
- Seasonal birth pulses
- 20 age classes
- Parameter estimates from Brook et al 2019

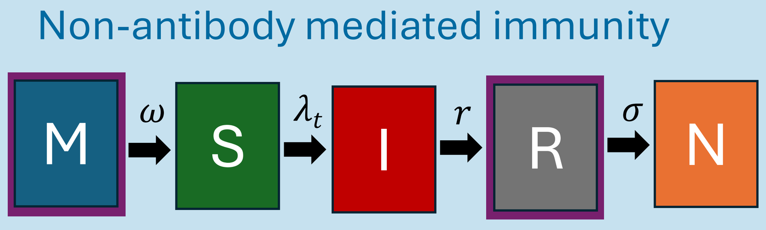
MSIRS

Waning Immunity



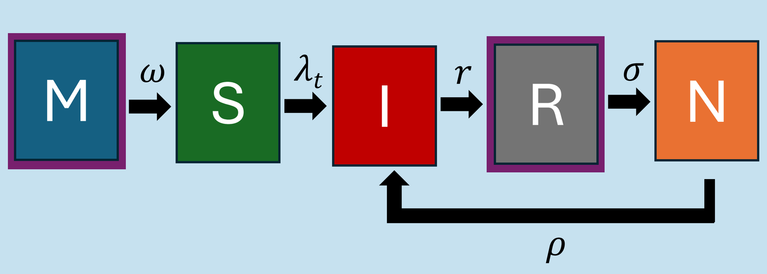
MSIRN

Non-antibody mediated immunity



MSIRNI

Persistent viral infection with recrudescence



seropositive

STATES

- M – maternally immune
- S – susceptible
- I – infected
- R – recovered
- N – non-antibody mediated immune

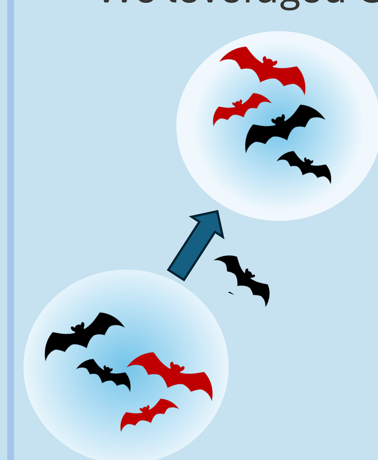
PARAMATERS

- ω – waning maternal immunity
- λ_t – force of infection at time t
- r – recovery
- σ – rate of antibody waning R to N
- ψ – rate of antibody waning R to S
- ρ – rate of recrudescence

SPATIAL MECHANISMS

We modified the model to allow for two mechanisms of subpopulation connectivity: **dispersal** and **intermingling**. We leveraged **GPS telemetry** to estimate these parameters.

DISPERSAL



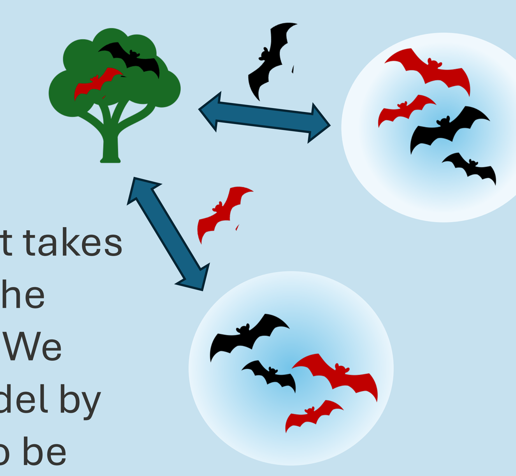
Dispersal is the movement of an individual from one subpopulation to another. We employ dispersal in the model by multiplying the population matrix at time t by a **matrix of dispersal probabilities**.

We generate the **matrix of dispersal probabilities** by:

1. For each bat, count the putative number of **roost switches**
2. For each bat, calculate the **daily probability of roost switching** (number of roost switches / number of days)
3. Calculate the **biweekly probability of roost switching** (binomial draw where p = average daily probability of roost switching)

susceptible
infected

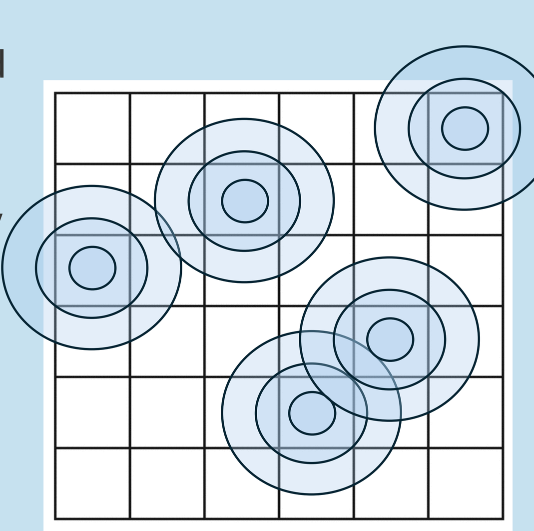
INTERMINGLING



Intermingling is interaction that takes place between bats outside of the roost, such as in a feeding tree. We employ intermingling in the model by allowing the force of infection to be influenced by infected bats from other subpopulations multiplied by a **probability of interaction** between the two subpopulations.

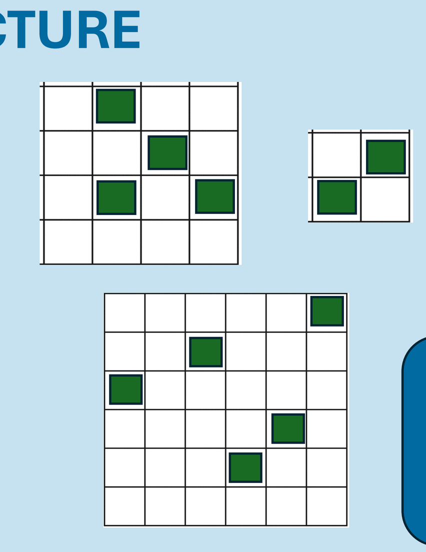
We generate the **matrix of interaction probabilities** by:

1. Calculate the average **utilization distribution kernel** (UD - the probability of finding the bat at any specific location within its home range)
2. Convert area of each 5% contour to **concentric circles of probability space** with the roost as the center point
3. Use the generalized utilization distribution and distance between each pair of patches to determine the **probability of intermingling** between two occupied patches



GRID STRUCTURE

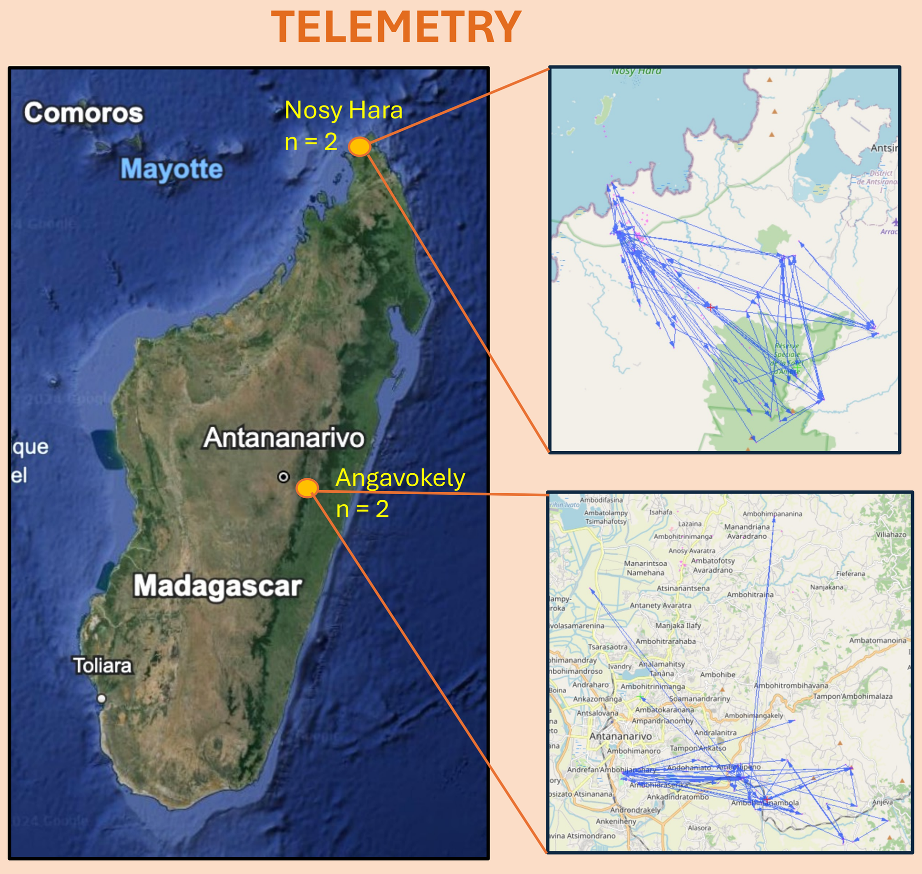
We generated a range of **grid structures** and **grid sizes**, with an **initial roost occupation** of 0.68 based on 2000's roost survey data. **Initial population size** and **location of occupied patches** are randomly drawn for each simulation.



I am actively seeking feedback on these spatial mechanism methods - please get in touch*!

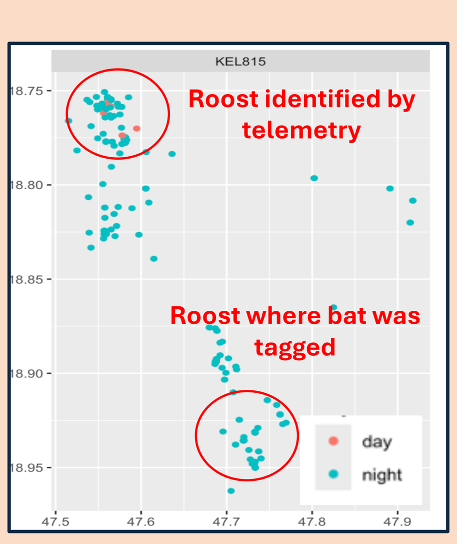
BAT MOVEMENT

TELEMETRY



Tracks from one representative bat.

DISPERSAL

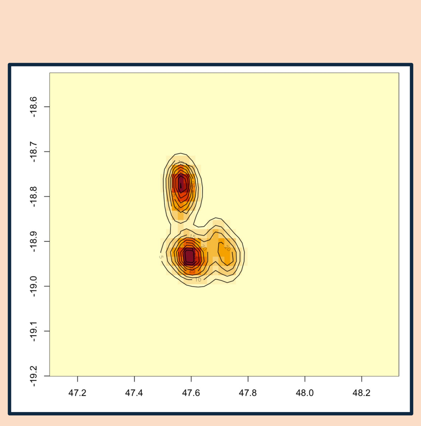


Example of how we counted number of roost switches; data from one bat.

We estimated a probability that a bat makes at least one roost switch within a 2-week period is 0.23. In this first set of simulations, bats are equally likely to disperse to any other patch across the grid.

INTERMINGLING

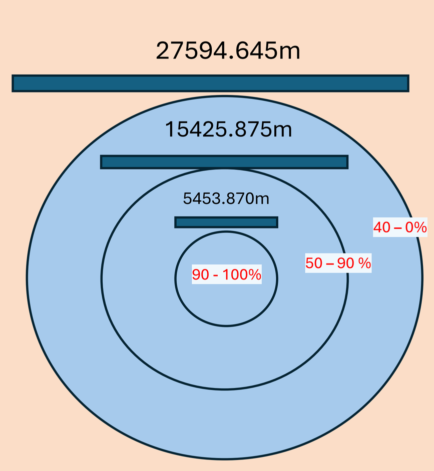
We generated a generalized utilization distribution from the two replicate bats from Angavokely, resulting in a UD with a diameter of 27,594m.



Site-pooled UD

	Angavokely
10	5453.870
15	6898.661
20	8089.397
25	9446.381
30	10631.551
35	11948.832
40	13134.659
45	14221.954
50	15425.875
55	16542.408
60	17756.516
65	19049.551
70	20406.515
75	21815.482
80	23394.498
85	25229.678
90	27594.645

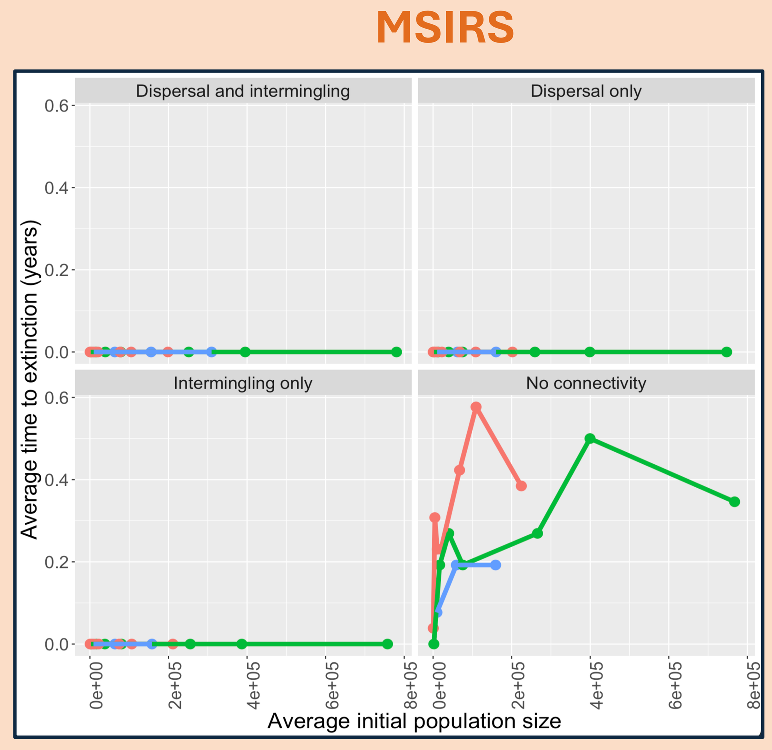
Area for each 5% UD contour



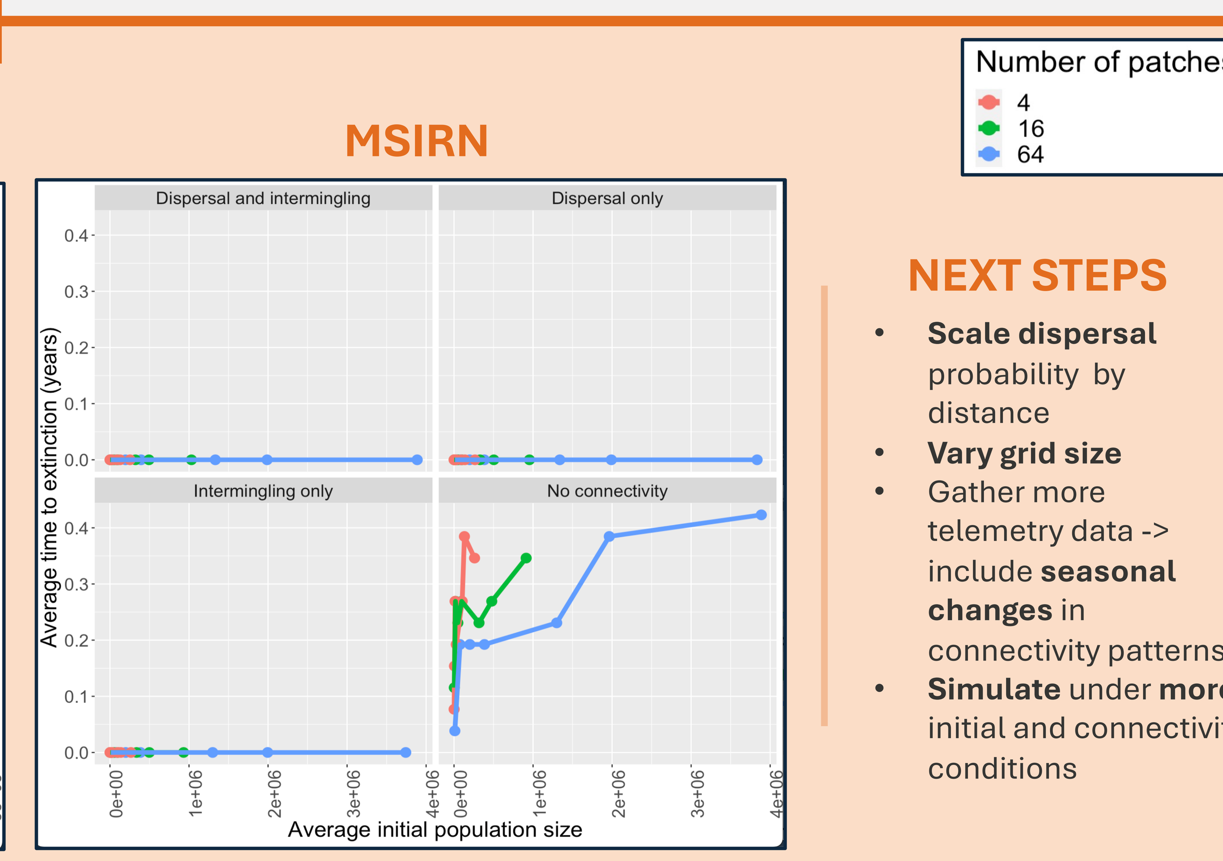
Generalized UD

MODEL SIMULATIONS

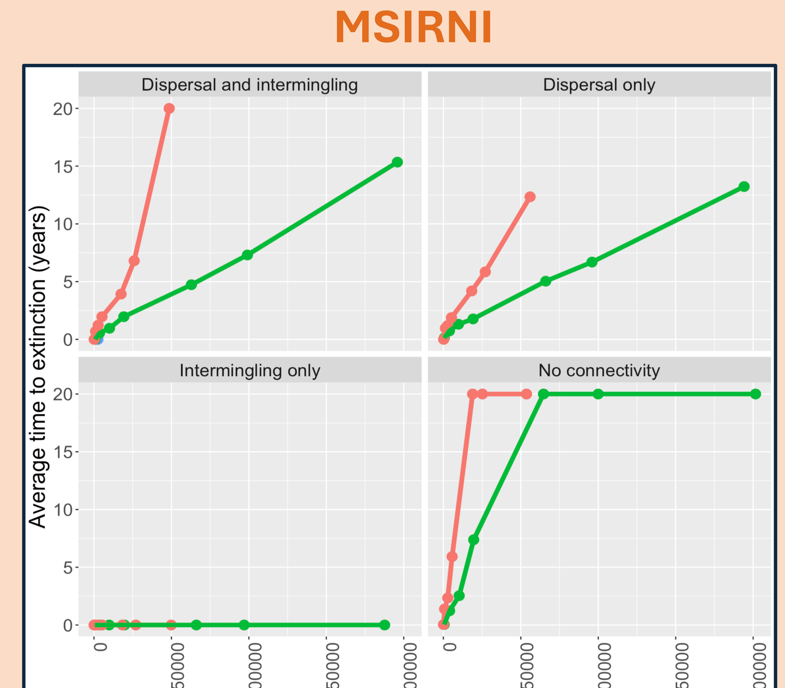
MSIRS



MSIRN



MSIRNI



Average time to extinction under different simulation types. 5 stochastic simulations of each set of initial conditions run for 20 years.

NEXT STEPS

- **Scale dispersal** probability by distance
- **Vary grid size**
- Gather more telemetry data -> include **seasonal changes** in connectivity patterns
- **Simulate** under **more** initial and connectivity conditions

FEATURES THAT...

Diminish persistence

- Smaller initial population sizes
- Larger number of patches
- Connectivity, particularly intermingling

Promote persistence

- Recrudescence
- Larger initial population sizes
- Fewer number of patches

I'M NOT SURE I BELIEVE THIS!

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THE UNIVERSITY OF CHICAGO Center for Global Health

WALDER FOUNDATION BIOTA GRANT

MADAGASIKARA VOAKAJY

We would like to thank Dr. Isabella Mandl, Dr. Daudet Andriafidison, Dr. Jon Epstein, Dr. Cecilia Sanchez, Dr. Morgan Kaine, and Miora Andriaiaina.