Investigating the persistence of infectious diseases in Hunter-Gatherers: A SEIRS modelling approach

MSc Project
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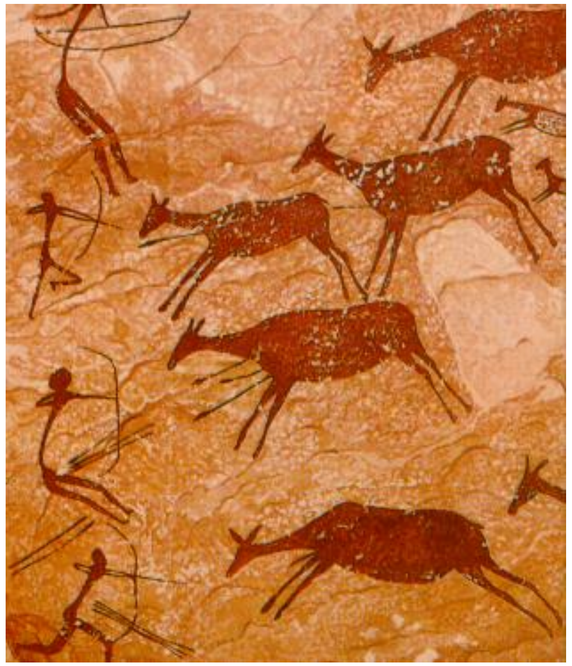
The Neolithic Revolution

~230,000 BP to ~11,300 BP



- Low population size and density
- High mobility

~11,300 BP to Present

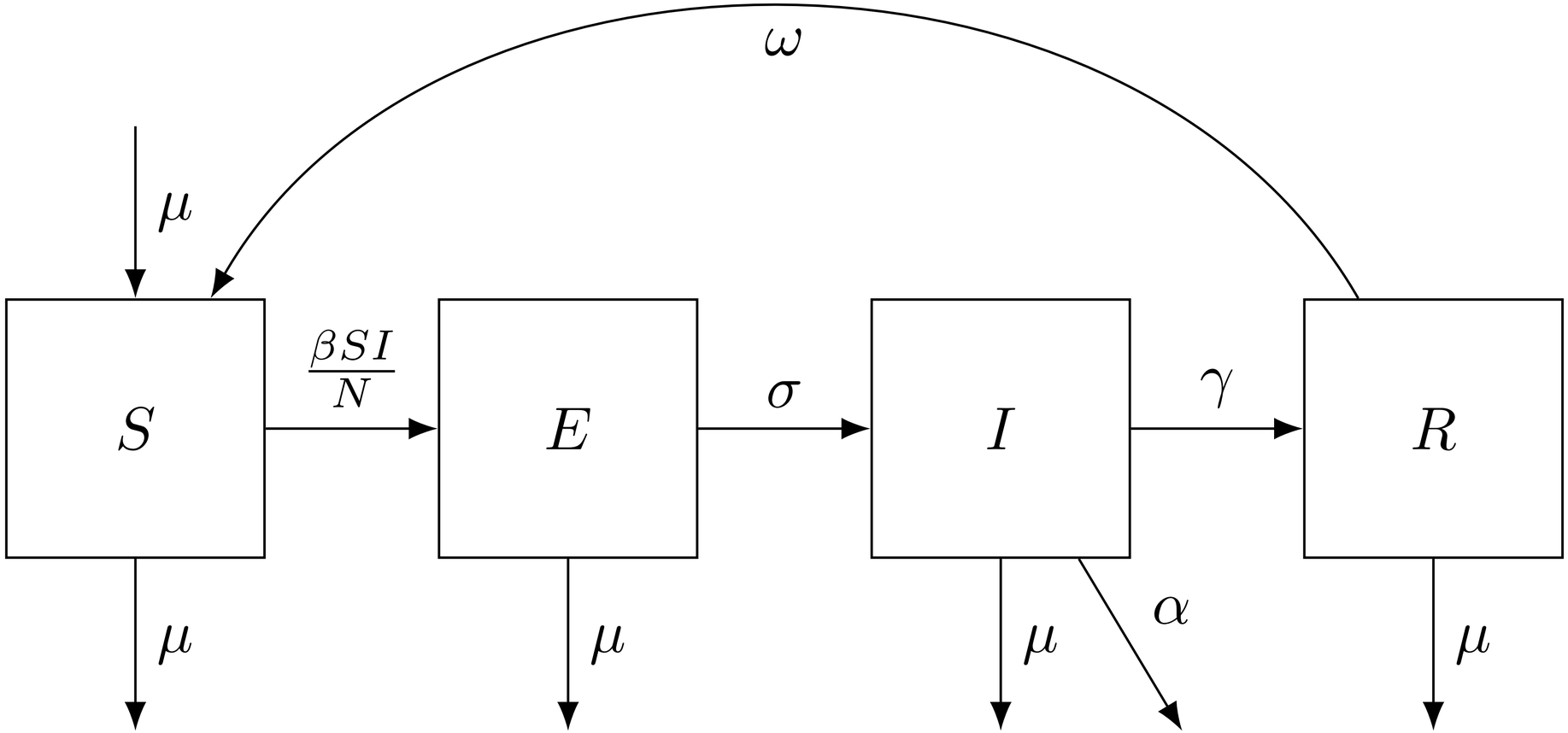
- Increased population size and density
- Low mobility
- Increased interaction with domesticated animals

What infectious diseases could persist in pre-agricultural hunter-gatherer populations?

More specifically, what are the host population and disease parameters necessary to sustain a pathogen in a population of hunter gatherers?

SEIRS Model

(Susceptible - Exposed - Infected - Recovered - Susceptible)



$$\frac{\mathrm{d}S}{\mathrm{d}t} = \underbrace{\mu N}_{\text{birth}} - \underbrace{\frac{\beta S I}{N}}_{\text{infection}} + \underbrace{\omega R}_{\text{lost immunity}} - \underbrace{\mu S}_{\text{death}}$$

$$\frac{\mathrm{d}E}{\mathrm{d}t} = \underbrace{\frac{\beta S I}{N}}_{\text{infection}} - \underbrace{\sigma E}_{\text{latency}} - \underbrace{\mu E}_{\text{death}}$$

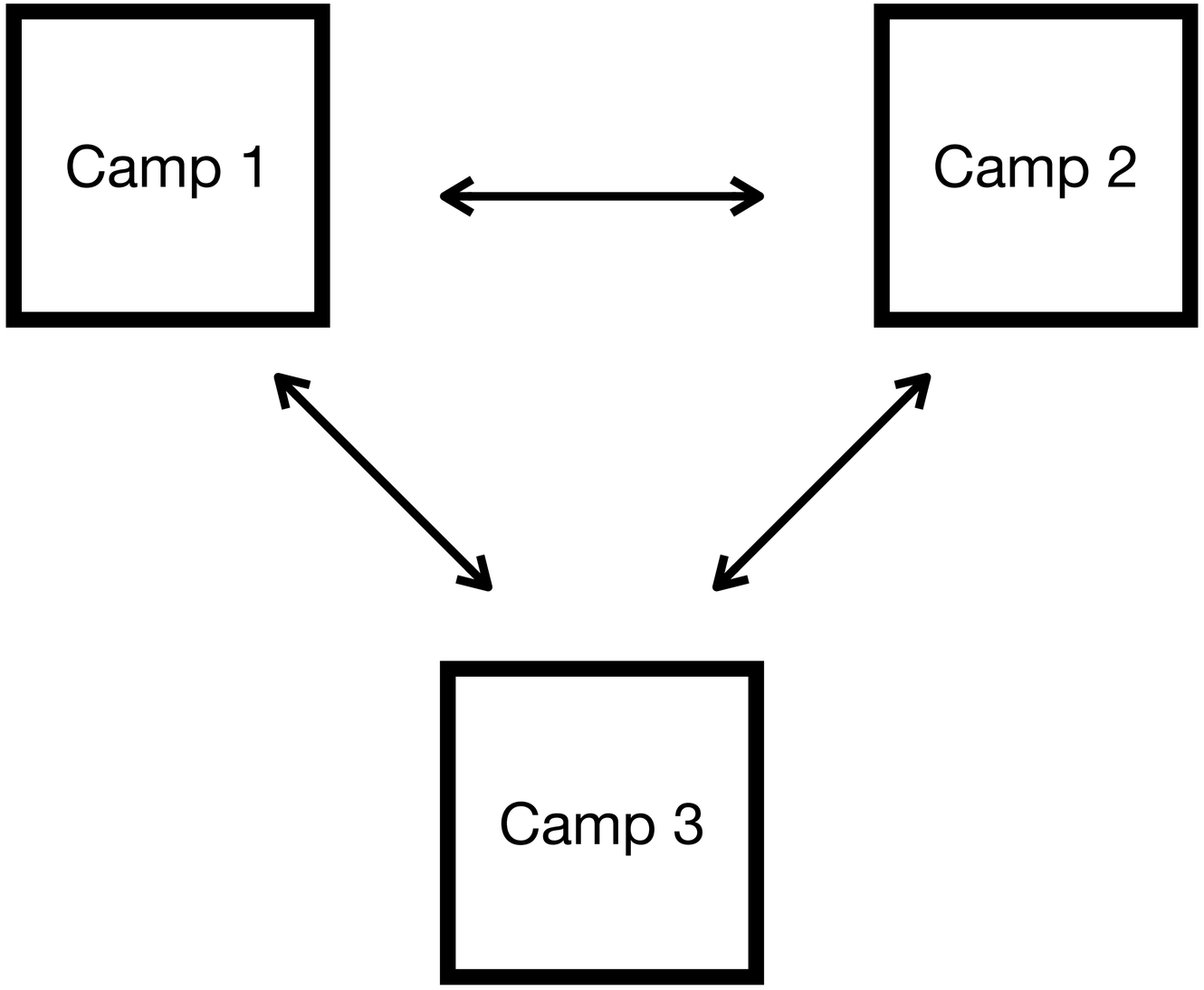
$$\frac{\mathrm{d}I}{\mathrm{d}t} = \underbrace{\sigma E}_{\text{latency}} - \underbrace{\gamma I}_{\text{recovery}} - \underbrace{(\mu + \alpha) I}_{\text{death}}$$

$$\frac{\mathrm{d}R}{\mathrm{d}t} = \underbrace{\gamma I}_{\text{recovery}} - \underbrace{\omega R}_{\text{lost immunity}} - \underbrace{\mu R}_{\text{death}}$$

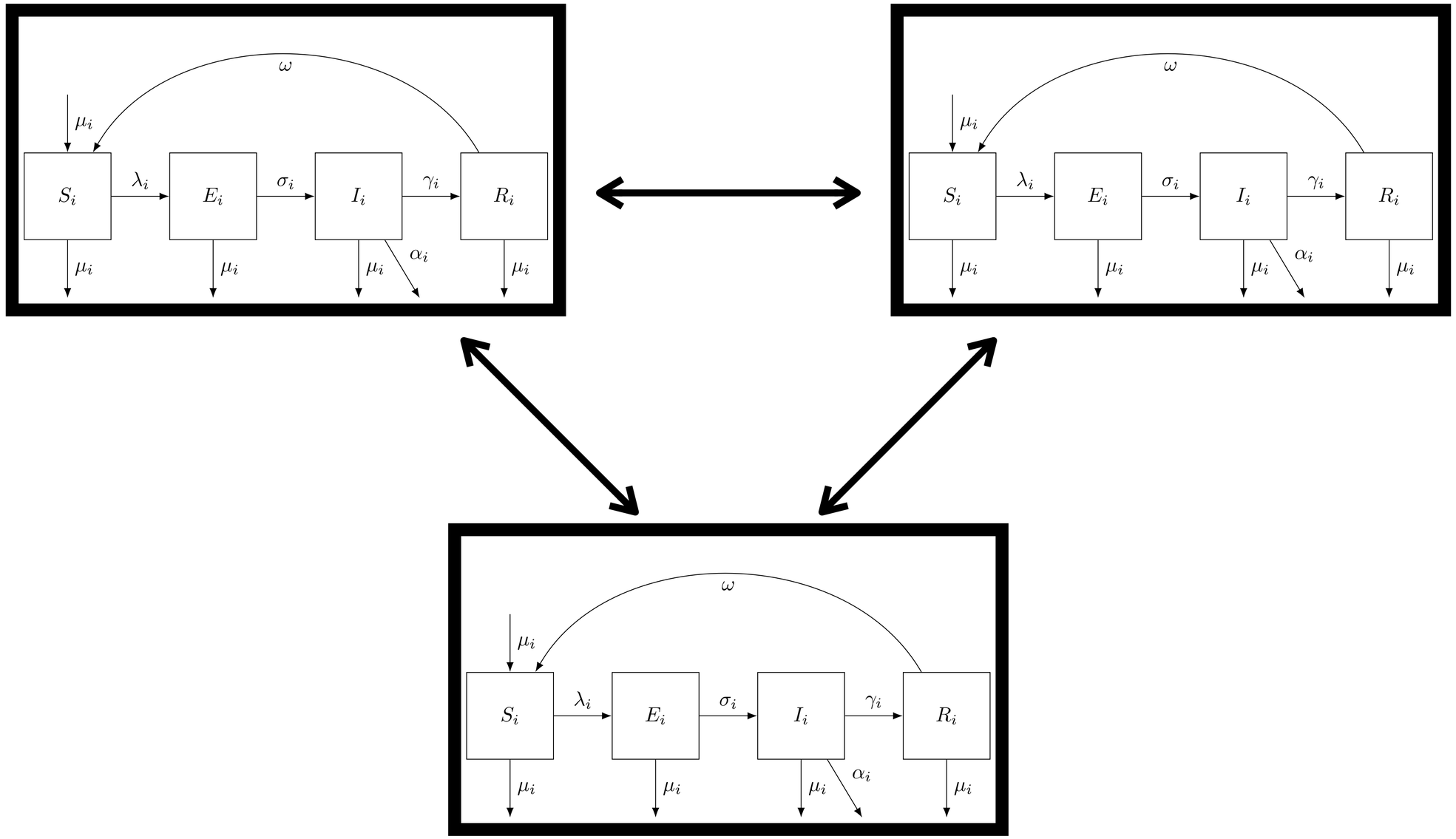
Where:

- μ is the birth/death rate
- β is the transmission coefficient
- σ is the rate of becoming infectious
- γ is the recovery rate
- ω is the waning immunity rate

Metapopulation Model



Metapopulation Model



Between Camp Transmission

$$\begin{bmatrix} C_{ii} & C_{ij} & ... \\ C_{ji} & C_{jj} & ... \\ ... & ... & ... \end{bmatrix} * b = \begin{bmatrix} \beta_{ii} & \beta_{ij} & ... \\ \beta_{jj} & \beta_{jj} & ... \\ ... & ... & ... \end{bmatrix}$$

Force of Infection → $\lambda_i = \left(\frac{\beta_{ii} I_i}{N_i} + \frac{\beta_{ji} I_j}{N_j} + ... \right) S_i$

Within-camp transmission ***Between-camp transmission***

Agta
Hunter-Gatherers

- Group of several indigenous peoples that live in the Northern Philippines
- Obtain food primarily through hunting and gathering
- ~10,000 total population
- Migliano et al. (2020) showed high levels of inter-camp connectivity facilitated rapid cultural evolution

Agta Demographics

- Birth rate = 0.0001 births/person/day (Headland et al, 2011)
- Average camp size = 41 (13-96 range) (Dyble et al. 2021)
- Between camp-contact rate approximately half of the within-camp contact rate (Migliano et al., 2020)

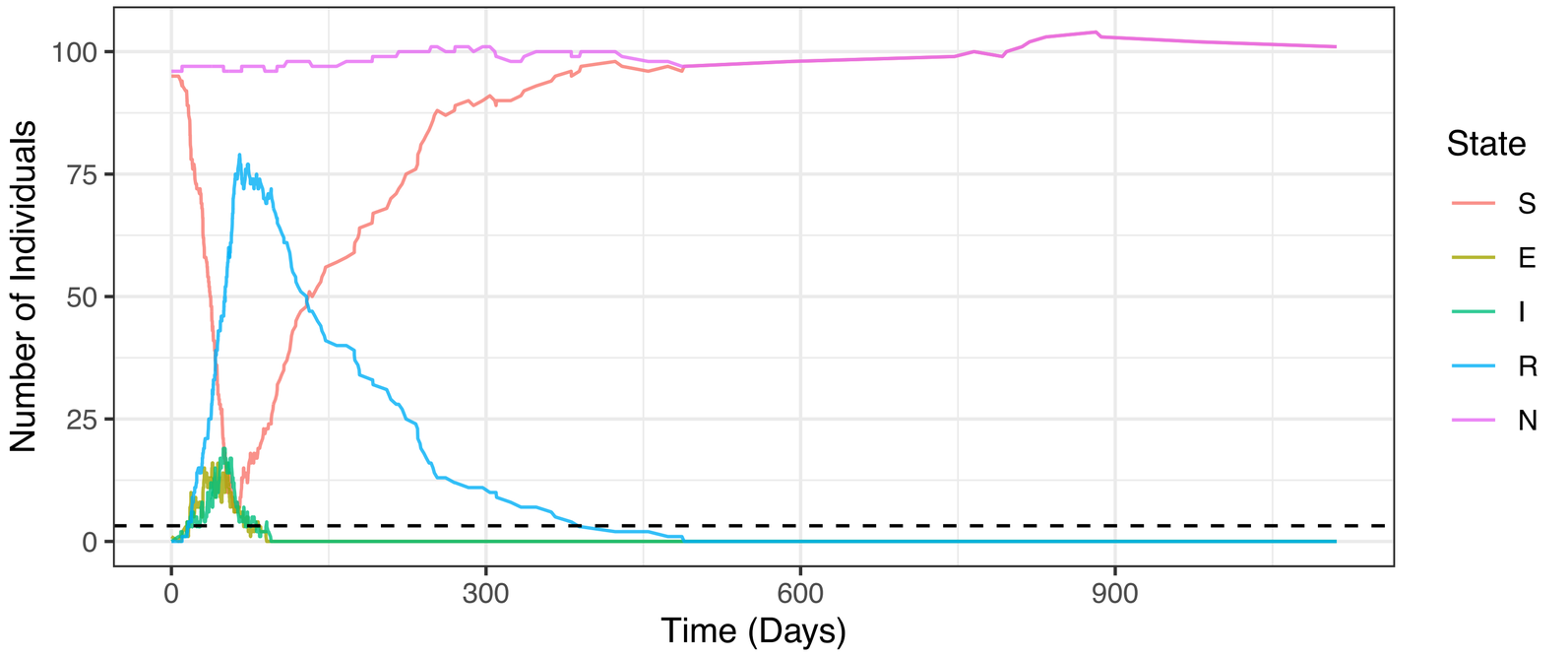
Parameter	Rate	Value
β	Transmission	0.6
σ	Infectious	0.175
γ	Recovery	0.2
α	Death from Infection	0.001
ω	Waning Immunity	0.01

Table 1: Parameters assumed for SEIRS transmission model of pathogen X.

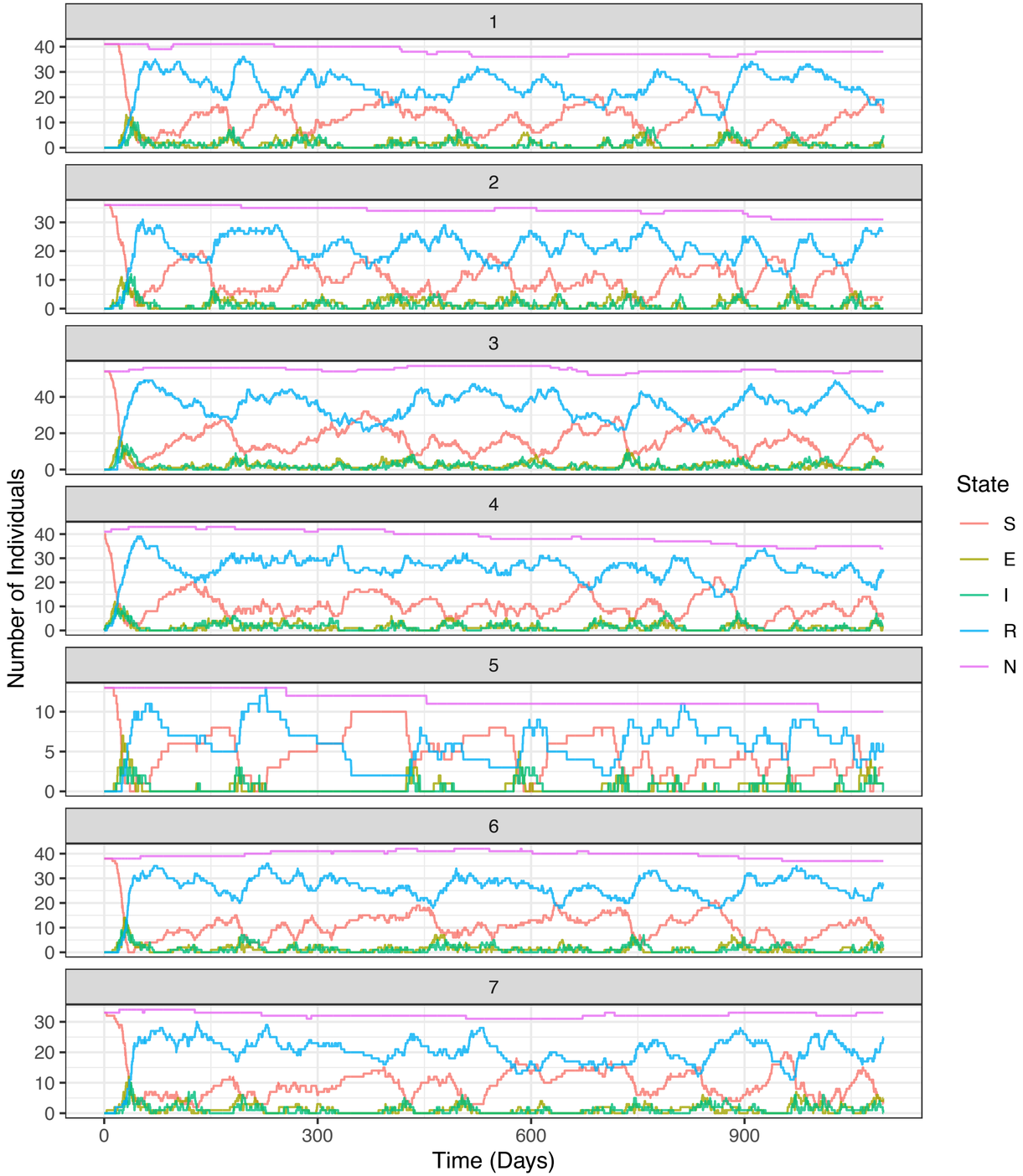
Stochastic Simulation

- Using the Gillespie algorithm
- Each model was ran for 3 years (1095 days) and simulated 1000 times
- Probability of persistence was defined as the percentage of runs with more than one infected after 3 years

Single Population



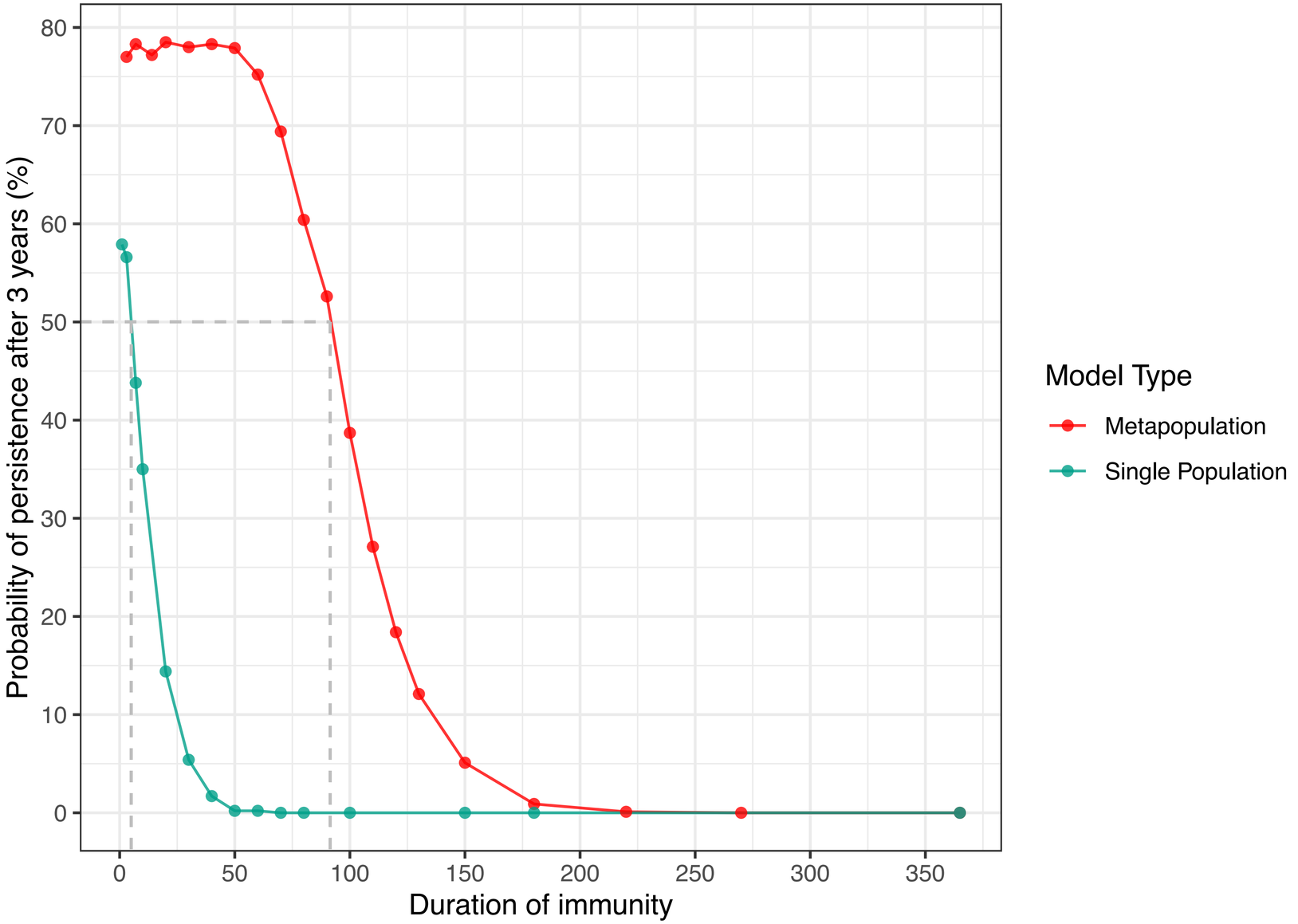
- Basic reproduction number (R_0) = 2.98
- Critical community size to sustain endemic spread = ~4,800,000
- Expected proportion of population infected at endemic equilibrium = 0.03
- Probability of persistence after 3 years = ~0



Metapopulation

- $R_0 = 4.29$
- Probability of persistence after 3 years = 38.6%
- Between camp transmission facilitates persistence through re-introduction

Waning Immunity



- Probability drops rapidly in single population model as duration of immunity is increased
- In the metapopulation model, probability stays ~78% from 1-50 day and drops there after
- Duration of immunity at 50% probability of persistence:
  - 3-7 days for single population model
  - 90-100 days for metapopulation model

Key Findings

- Multi-camp structure of hunter-gatherer groups can facilitate the persistence of a highly infectious pathogen with waning immunity

- Effect of metapopulation structure depends on replenishment of susceptible (i.e. through waning immunity)

Next Steps

- Effect of other parameters should be investigated
- Different model types should be tested
- More realistic contact rates generated

Questions?