A quantitative simulation-based evaluation of the early detection of poliovirus using environmental surveillance

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Speaker disclosure

We have no actual or potential conflict of interest in relation to this presentation.

Background

Polio Epidemiology

- Wild poliovirus is endemic only in Pakistan and Afghanistan in 2023.

- In 2020, polio-free status was certified in African continent.

However, 8 sporadic cases were reported in Mozambique in 2022,

which were genetically linked to the Pakistan strain.

→ Importation risks are still present in many countries.

Background

Two types of surveillance

- AFP (acute flaccid paralysis) surveillance
- Environmental surveillance (ES)
  - Identify the presence of polio including asymp.
  - Covered areas are limited, and can not trace who.

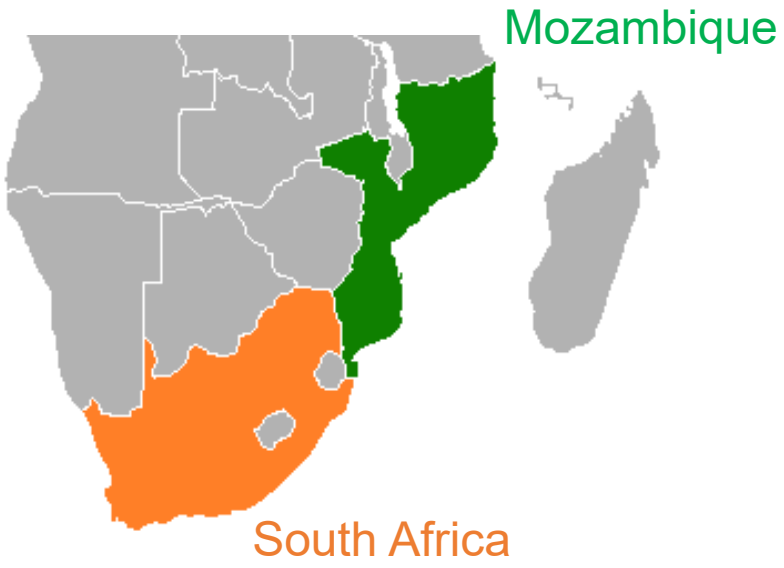
ES is mainly used for

- Confirmation of polio-free status
- Early detection over AFP surv.

Objective

Assess **the early detection ability** of ES over AFP surveillance
in a polio-free country by varying the size of **ES catchment area**

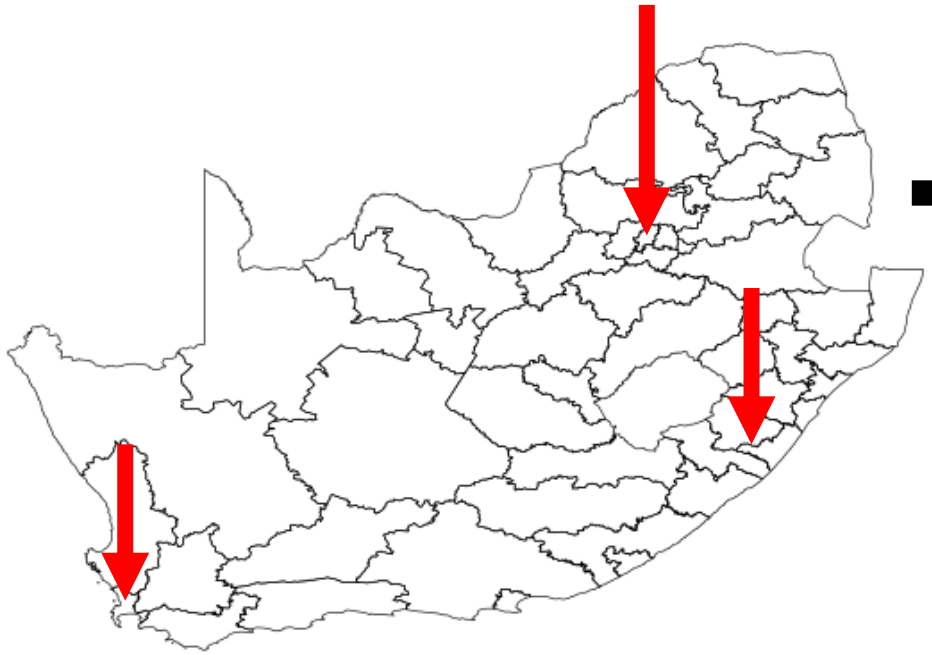
→ As a showcase,
we assume WPV1 introduction to South Africa



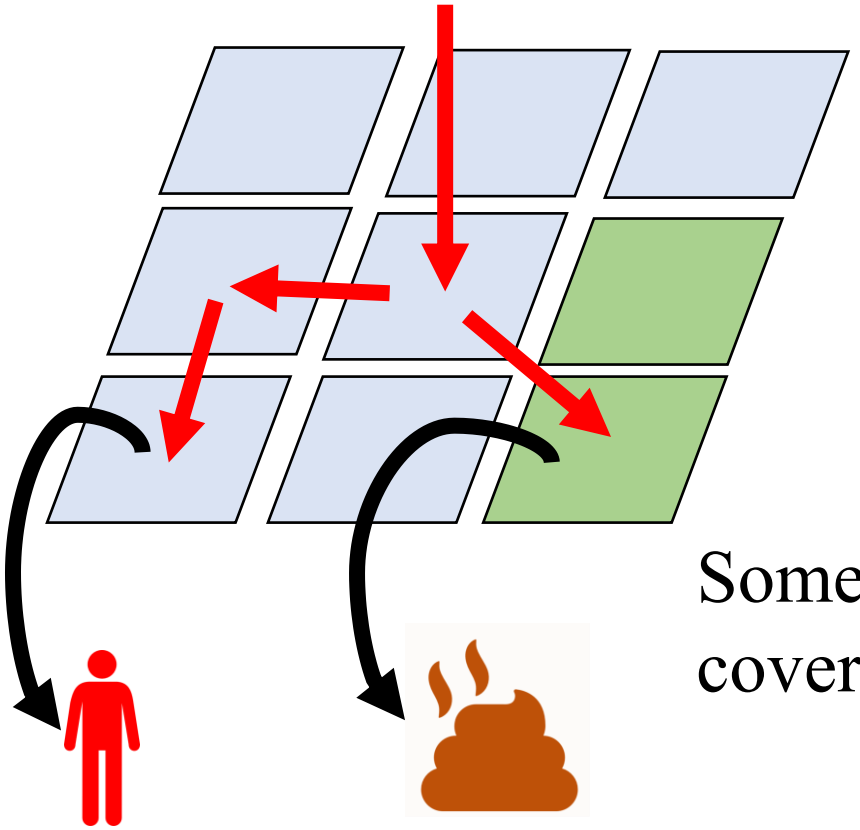
Concept

Apply stochastic simulations

Introduce WPV1 to a certain area



Spread between grids

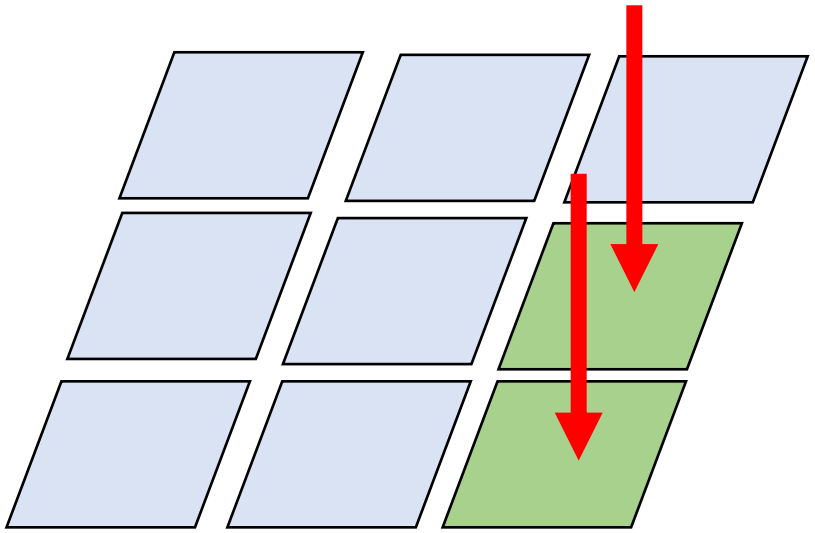


Some grids are covered by ES

Detected through AFP surveillance or ES

Concept

We assume ES performs better than AFP surveillance for a single grid.



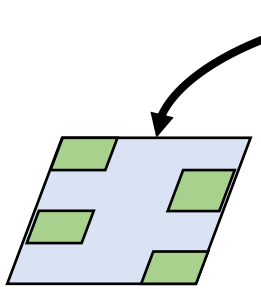
ES performs better
because of our assumption!

Key consideration:
- ES catchment area → Descending order of population size.
- Importation scenario → 3 patterns.

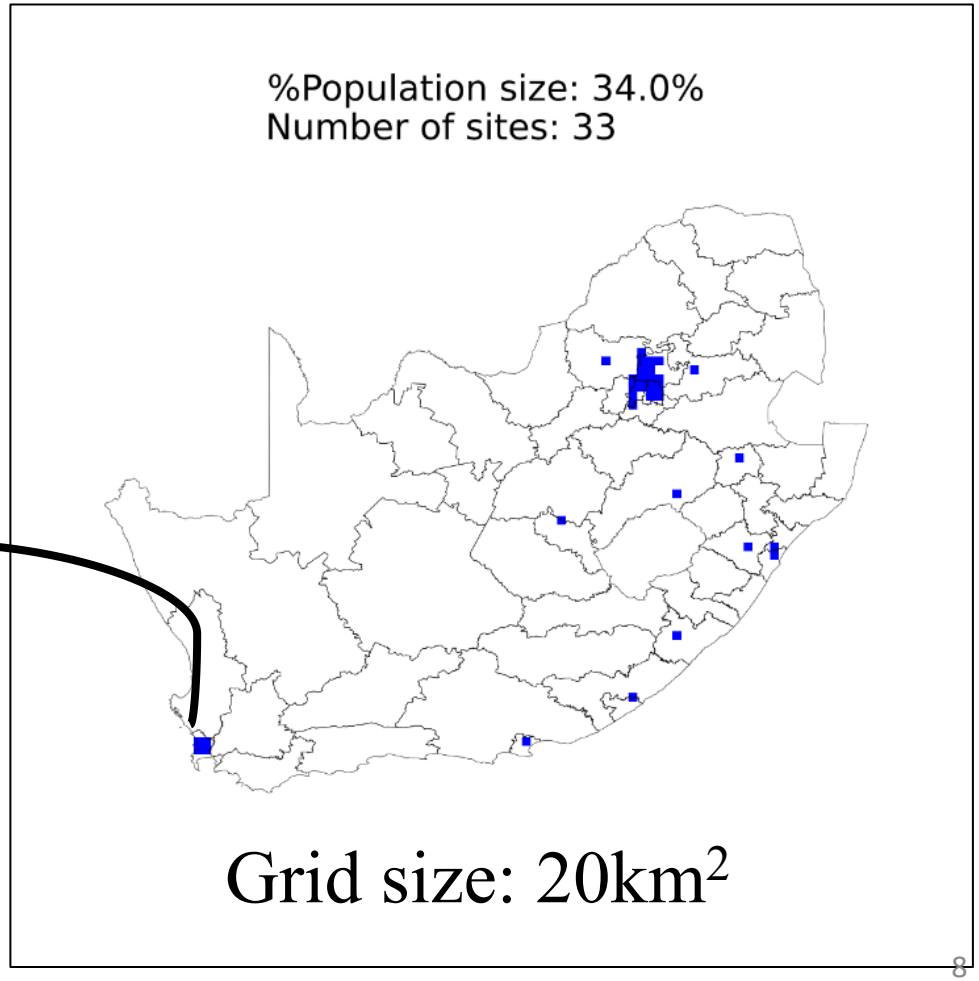
Adjust setting with the real ES catchment area

South Africa has 16 ES sites in 8 districts,
covering 8.6% population.

Among districts with ES,
average 25% coverage.



25% coverage
within a grid



Grid size: 20km^2

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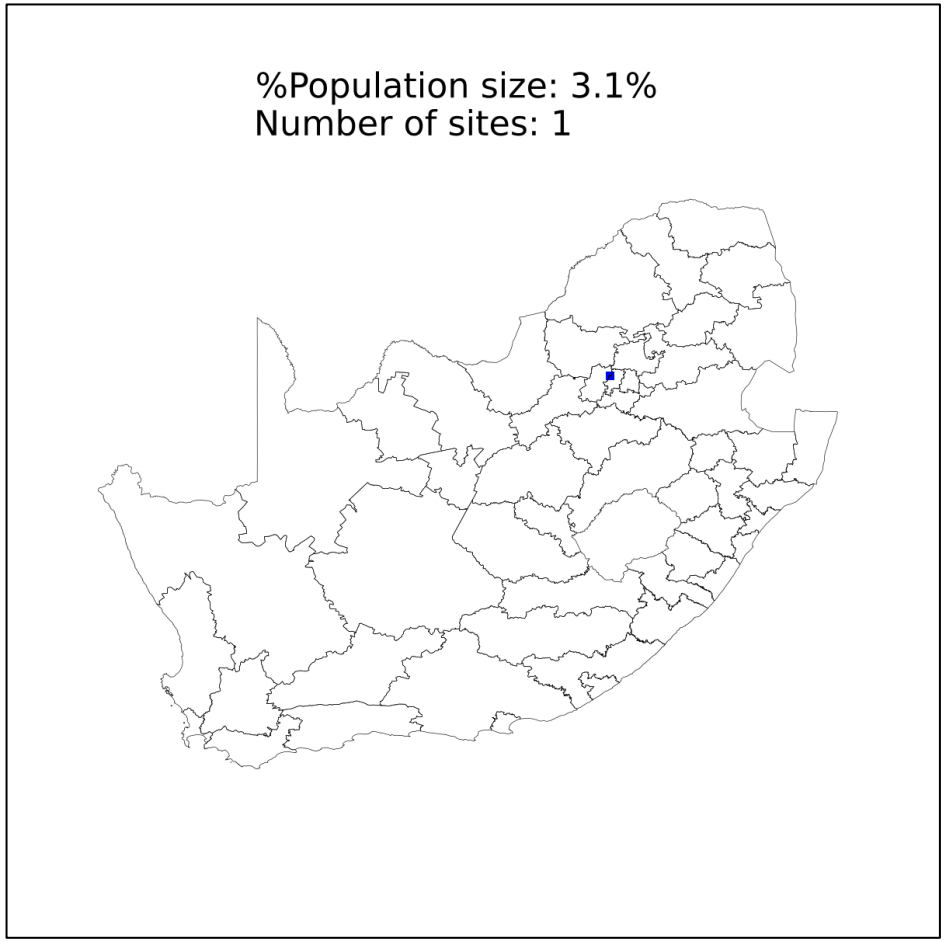
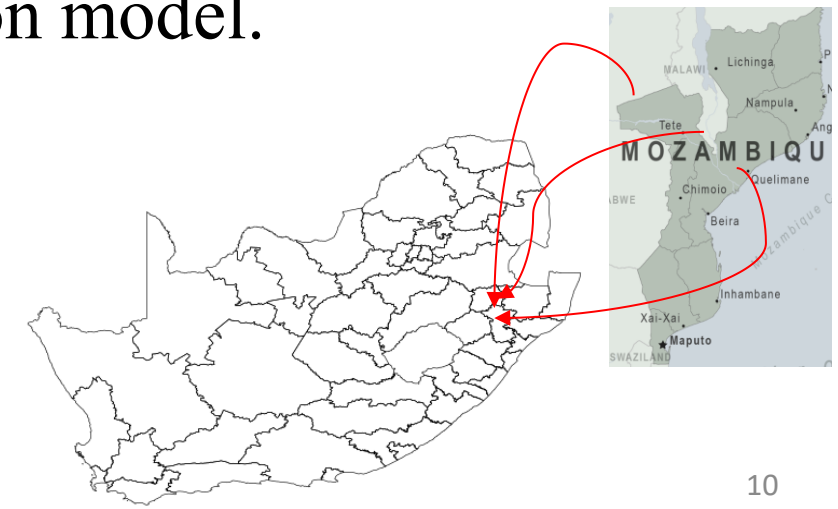


3 importation scenarios

1. **Population size scenario**: Probability of importation is proportional to population size in each grid.

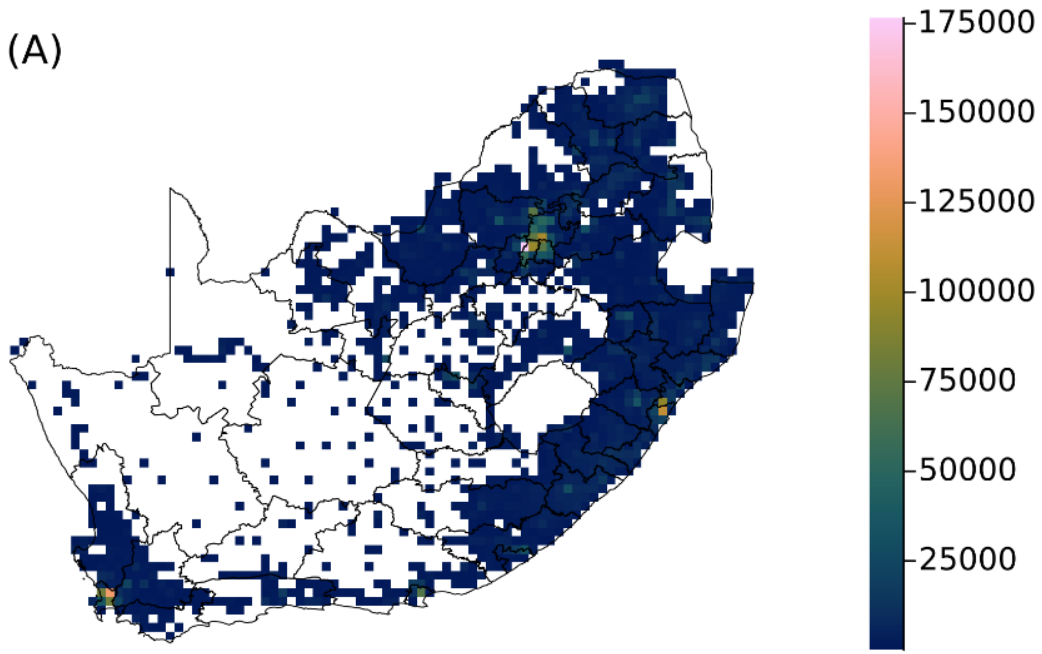
2. **Airport scenario**: Importation only happens in 3 international airports.

3. **Mozambique scenario**: Importation source is Mozambique, and the probability is calculated by the radiation model.

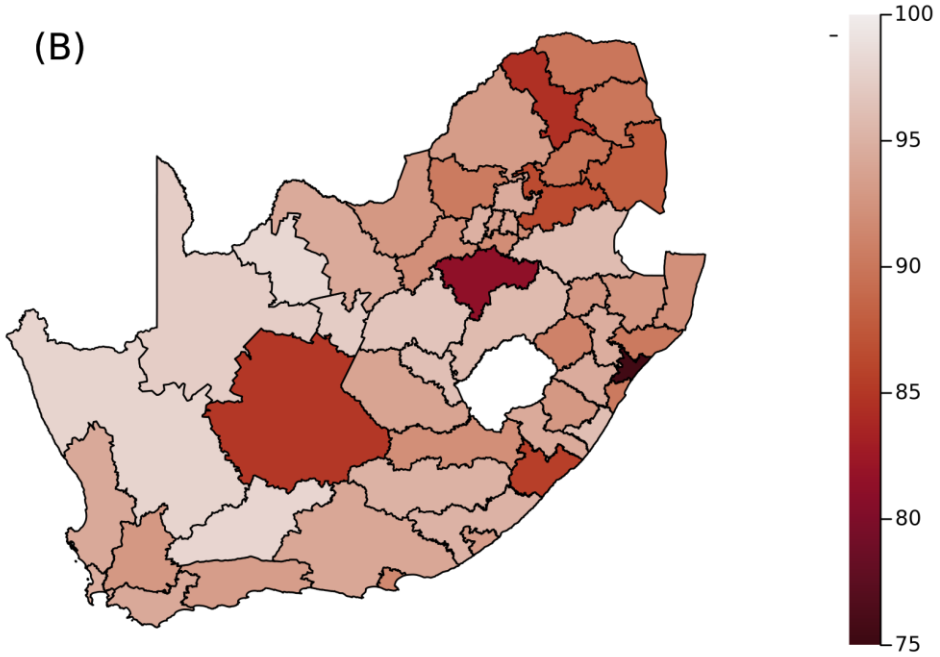


Population and vaccination coverage data

Population size (from WorldPop)



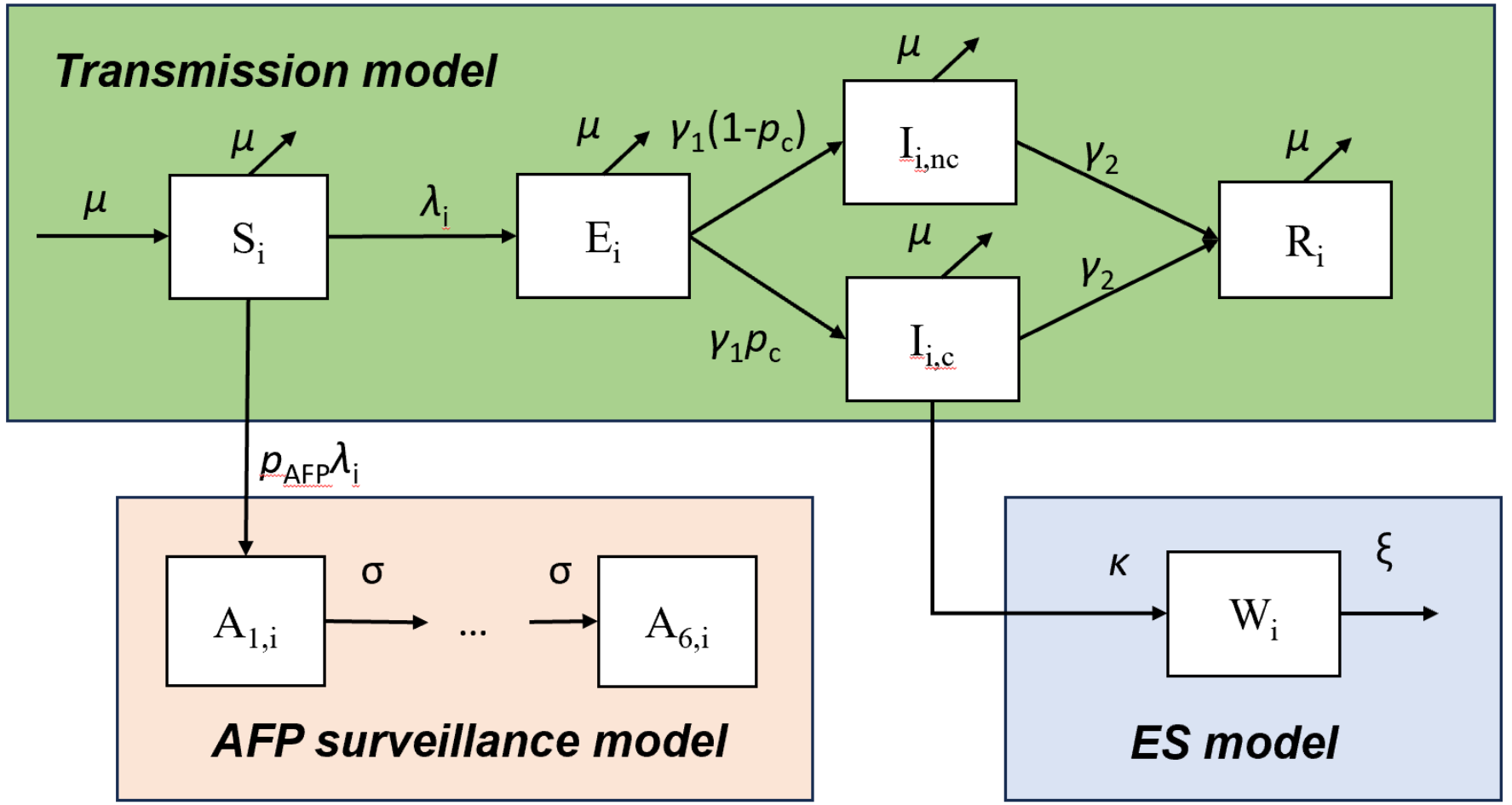
Vaccination coverage (in 2020 survey)



- Include children under 5 years old.
- Remove grids with <100 population size

Stochastic spatiotemporal model

SEIR model, distinguishing I compartments for ES to cover or not.



Transmission model

Force of infection

$$\lambda_i = \frac{\beta}{N_{u,i} + N_{v,i}} \left[(1-\alpha) I_i(t) + \alpha \sum_{j \neq i} \pi_{ji} I_j(t) \right]$$

Since South Africa routinely uses OPV + IPV,
vaccinated individuals, $N_{v,i}$, contribute only to herd immunity.

The probability of mobilisation between sites, π_{ij},
are obtained by the radiation model

AFP surveillance and ES model

AFP surveillance model

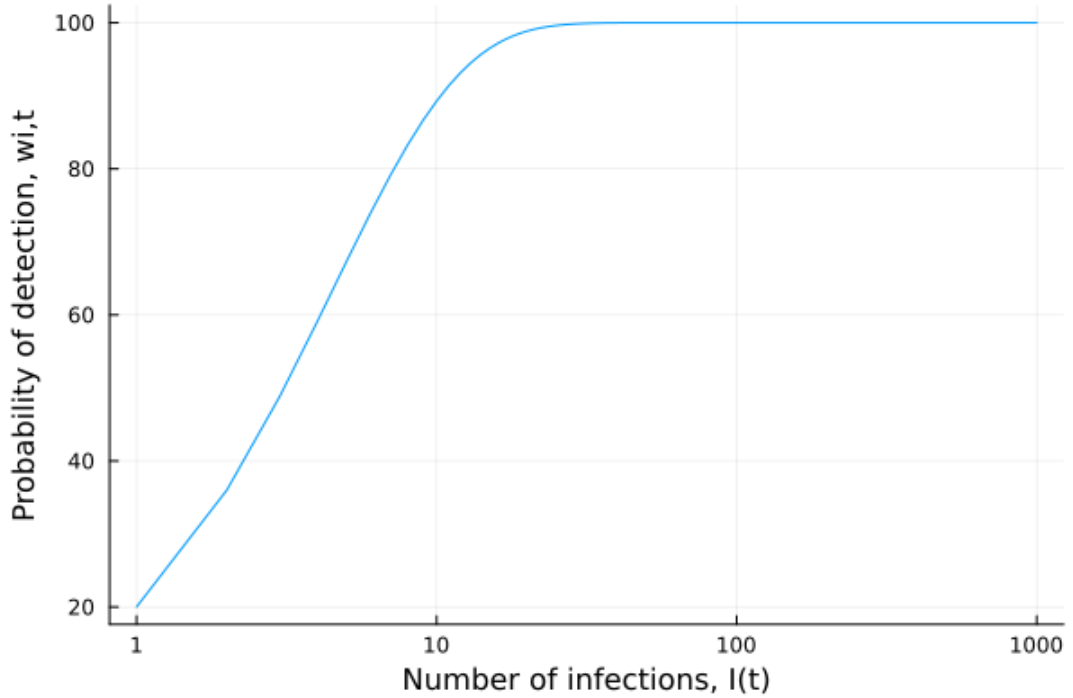
Binomial sampling of patients developing AFP, considering the probability of

- Seeking health care, 0.9
- Stool sampling rate, 0.53
- Sensitivity of polio detection for stool testing, 0.97

ES model

Binomial sampling of infected individuals, every 30 day.

If 10 infected individuals in a grid, 90% probability of detection



Outcomes have 6 categories excluding no detection

Among 5000 stochastic simulations,
4 detection patterns

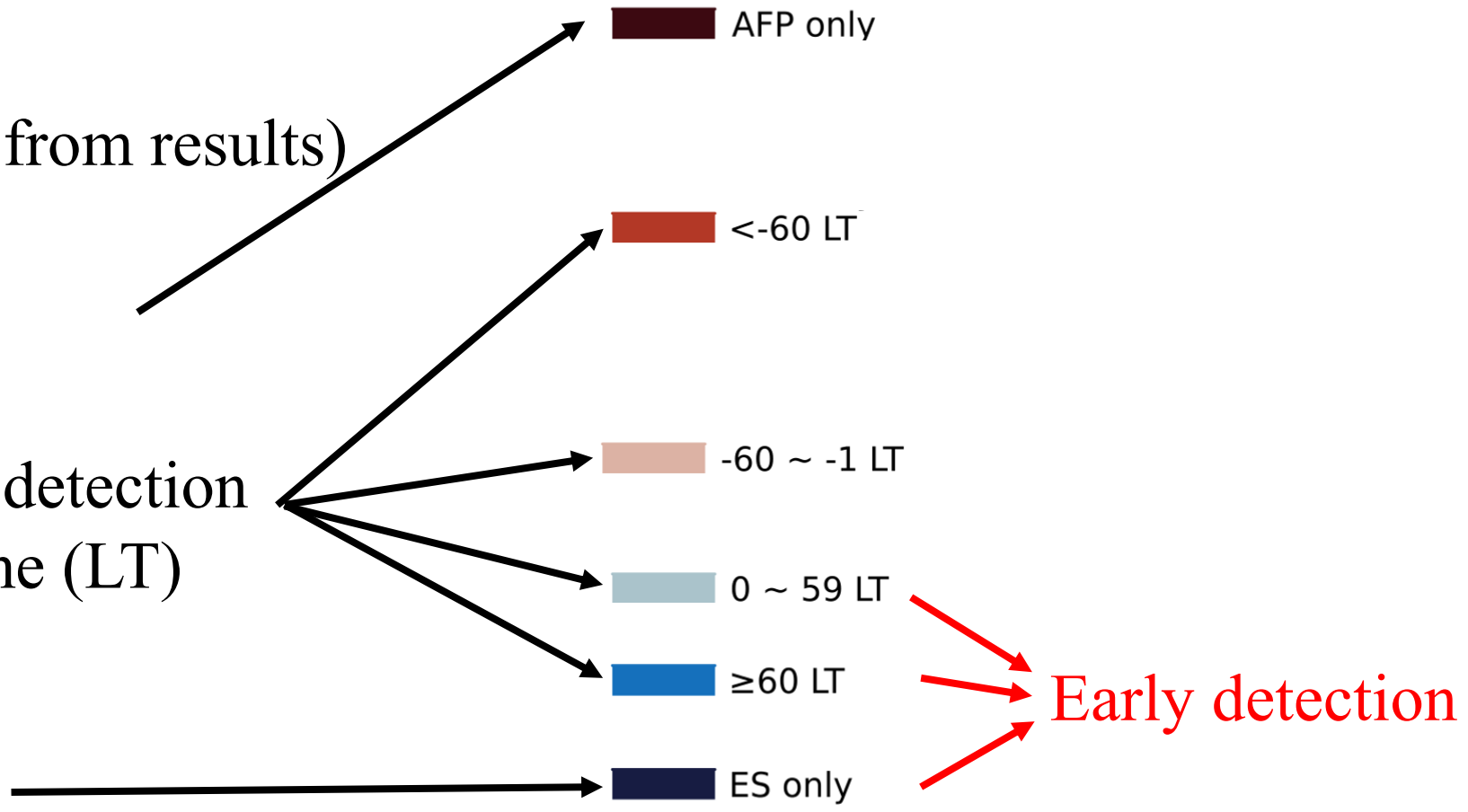
1. No detection (excluded from results)

2. AFP only detection

3. Both AFP surv. and ES detection

$t_{AFP} - t_{ES}$ = Lead time (LT)

4. ES only detection



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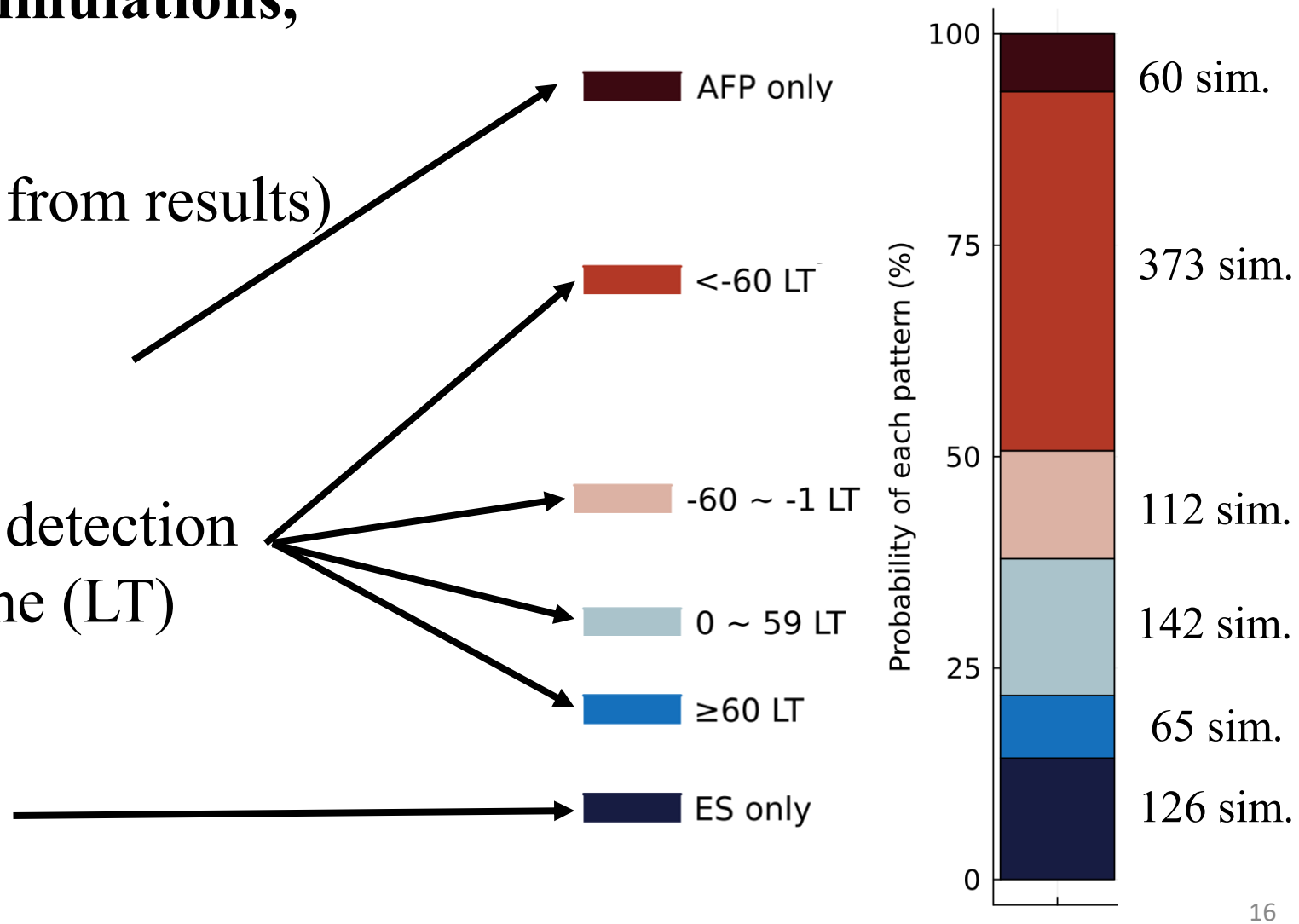
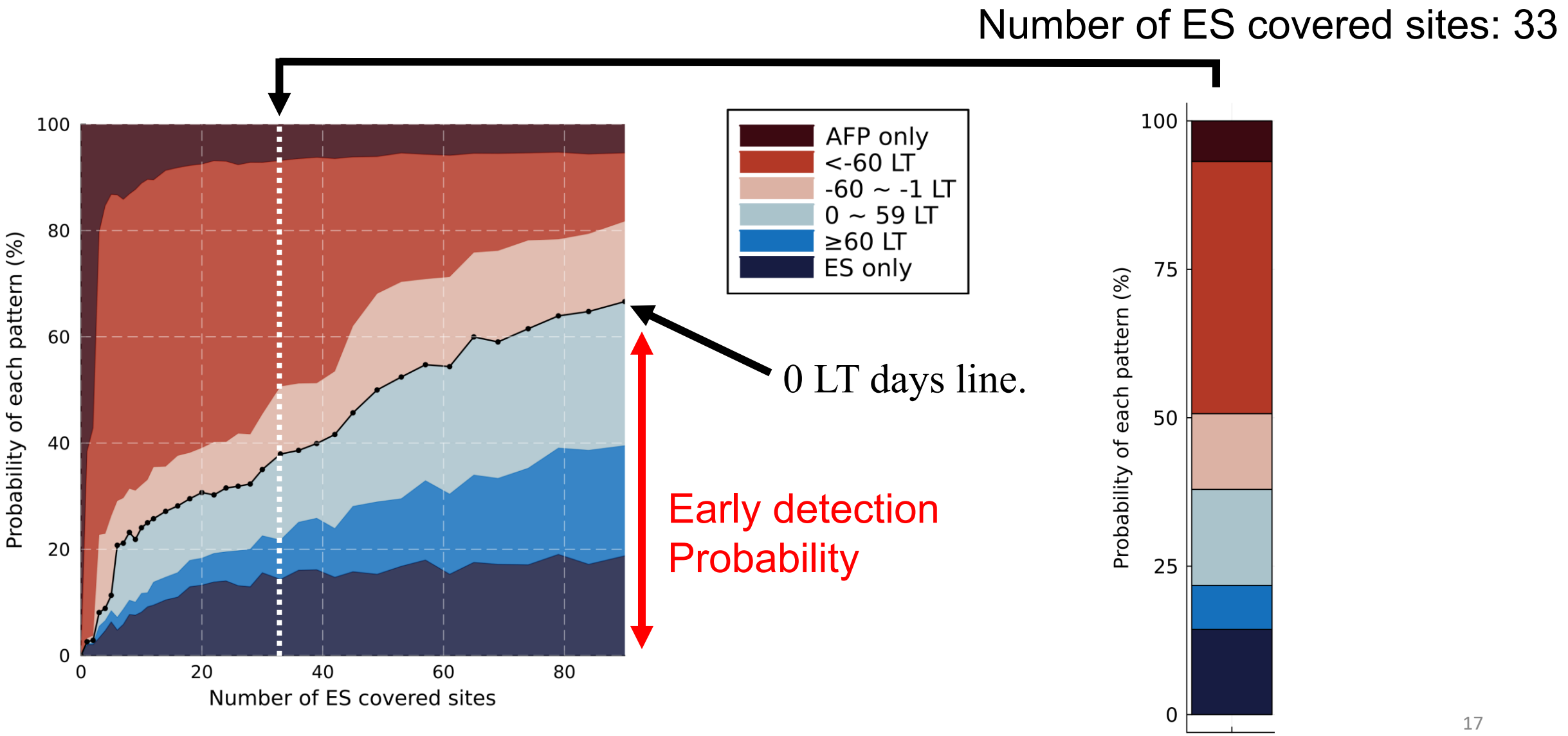
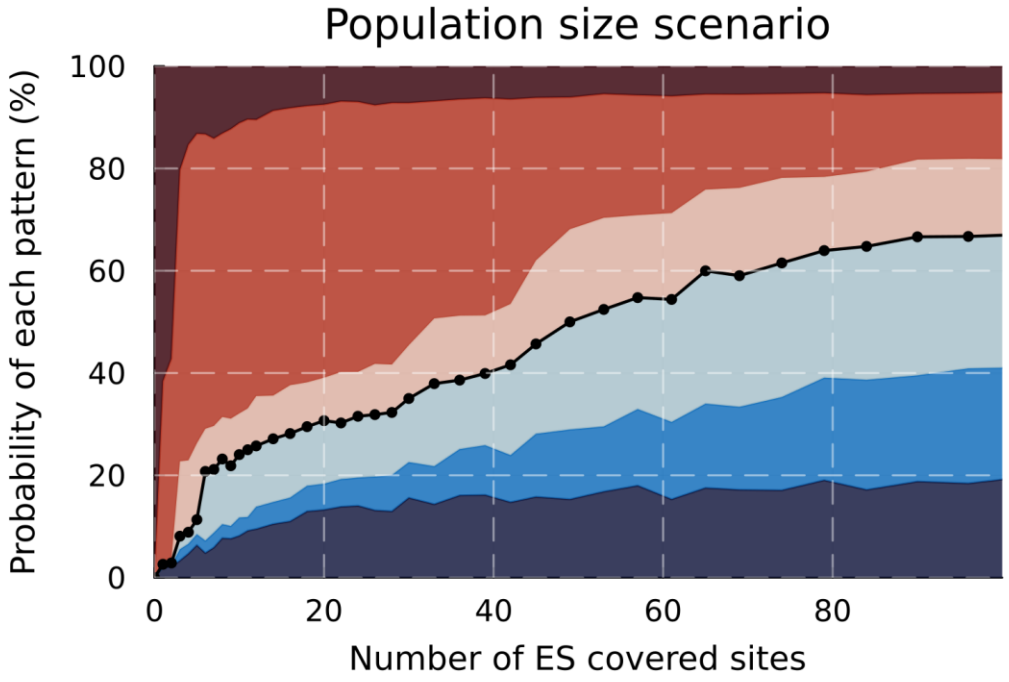
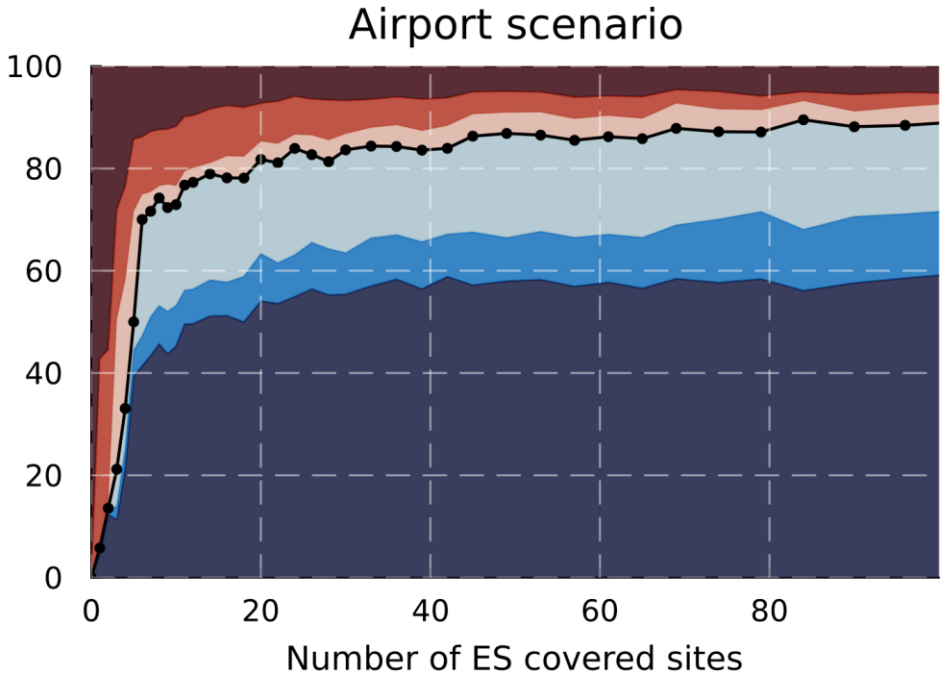


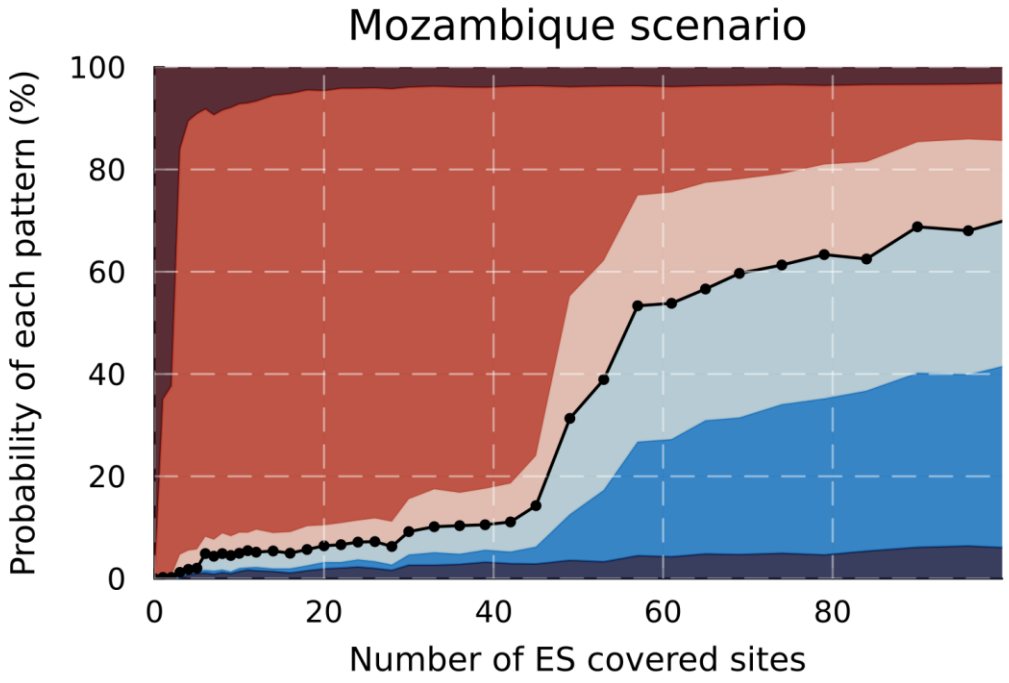
Heatmap varying # of ES-covered sites

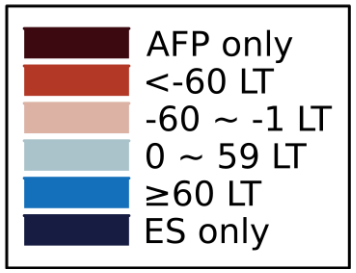


Results





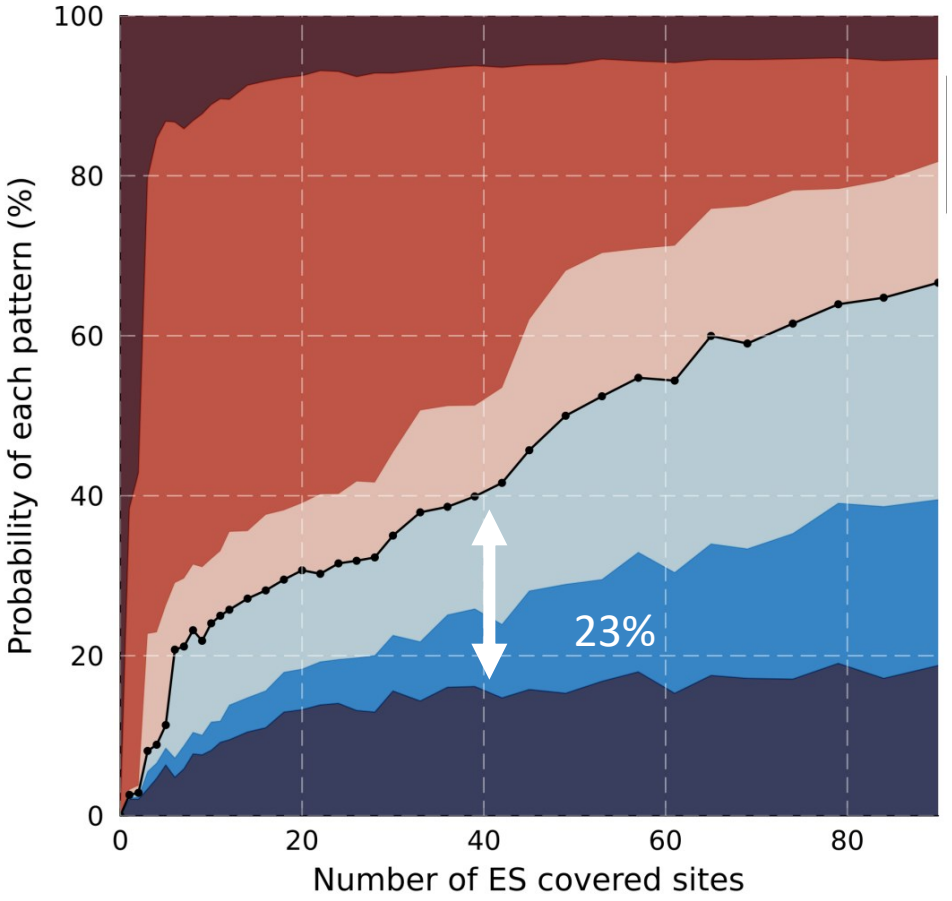




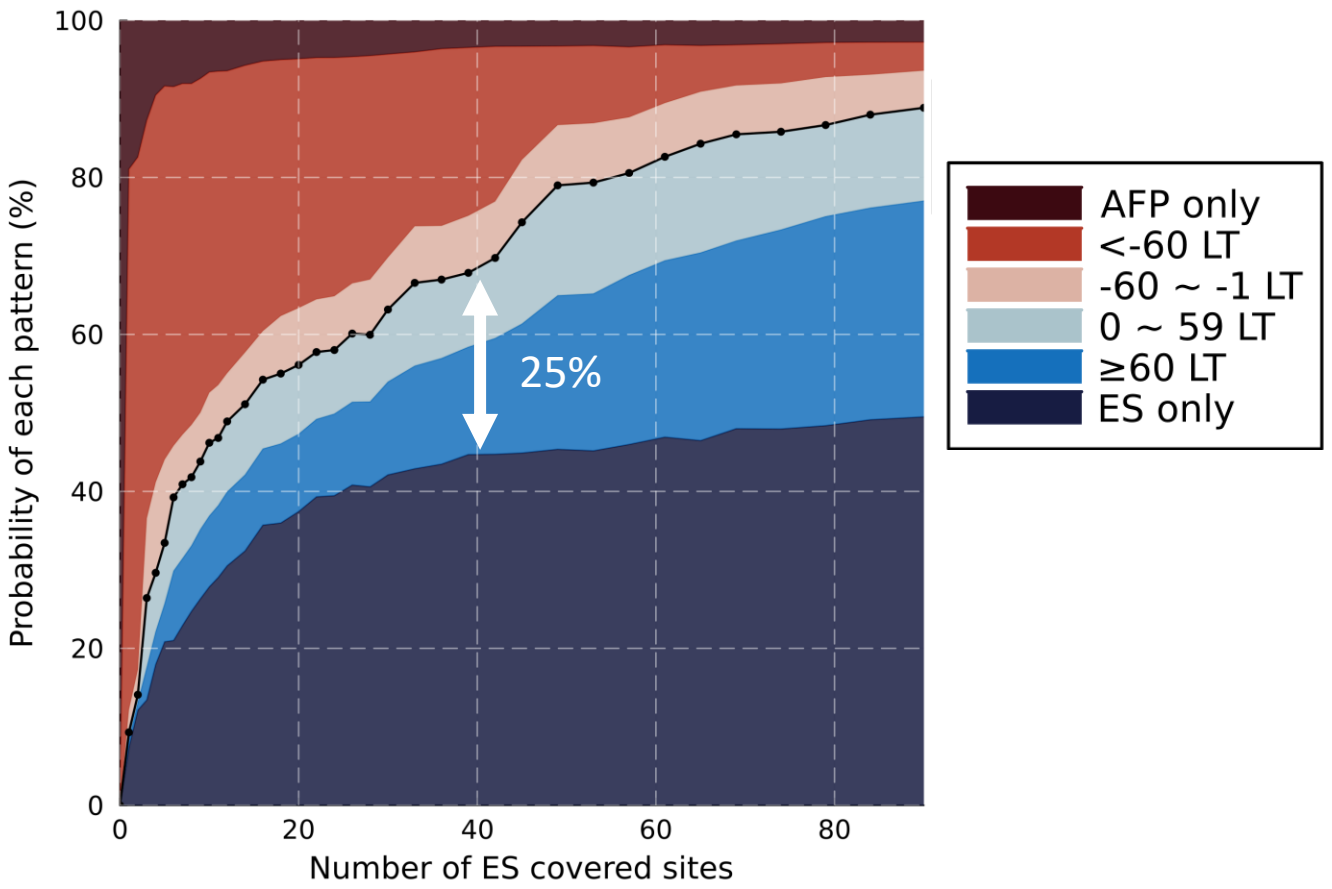
Depending on the importation scenarios, early detection ability is changed largely.

Frequent sampling increased early detection probability but not >0 LT detection much

Sampling frequency = 30 days



Sampling frequency = 1 day



Conclusions

From the perspective of the early detection,

- Importation risk assessment is important.

- To achieve 50% probability of early detection,
  10 ~ 50 ES covered sites are required, **which is quite large.**
  Note: 1 site has 20km^2 areas in our model.

- Wide area coverage of ES with moderate quality is better than narrow area coverage with high quality.

Limitations

- We consider the children <5 years old,

  but in a polio-free country, adults will be also infected.

- IPV and OPV coverage estimates have a large uncertainty.

  Gaps are present between IPV and OPV coverage.

Thank you

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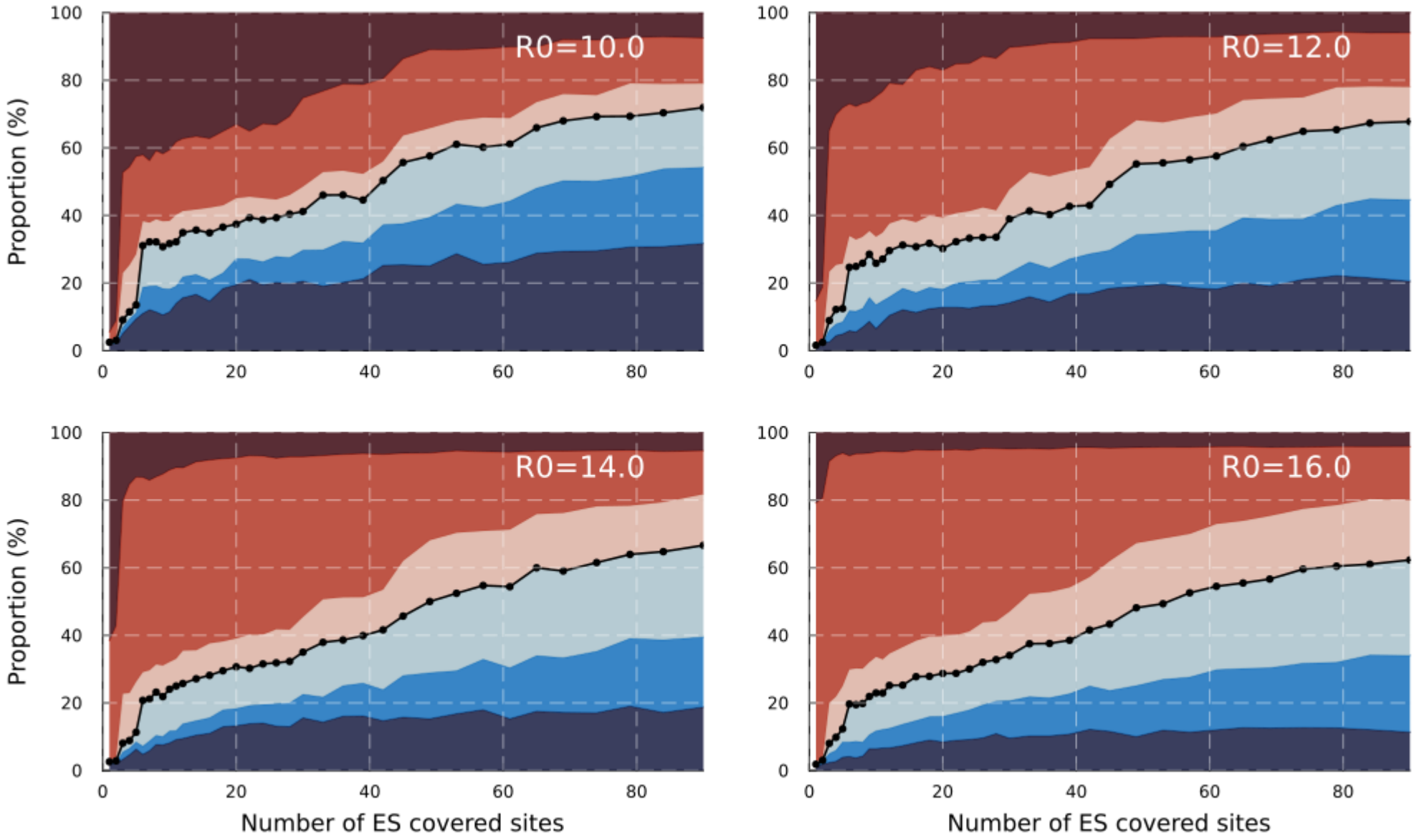
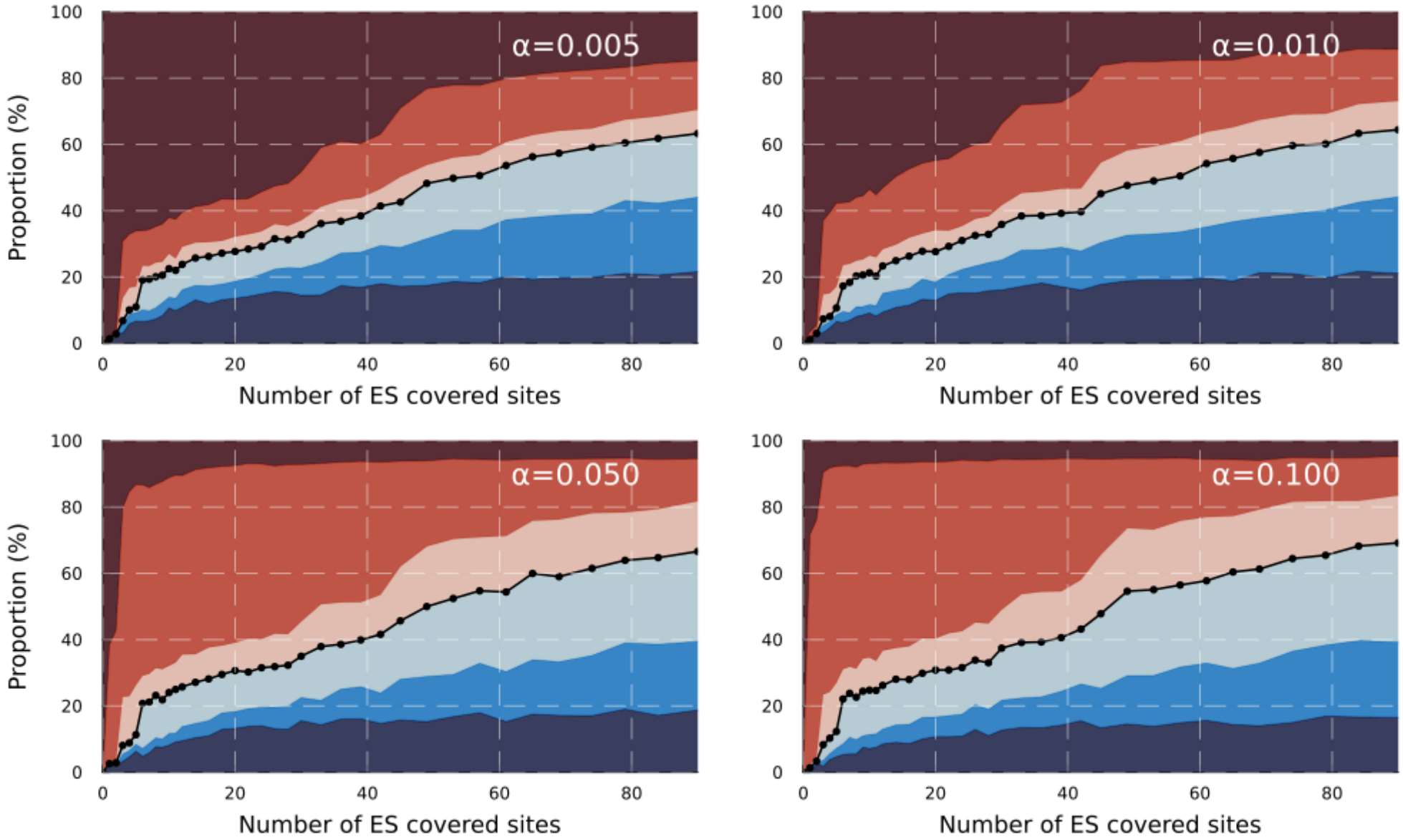
BILL & MELINDA GATES foundation

The Rotary Foundation

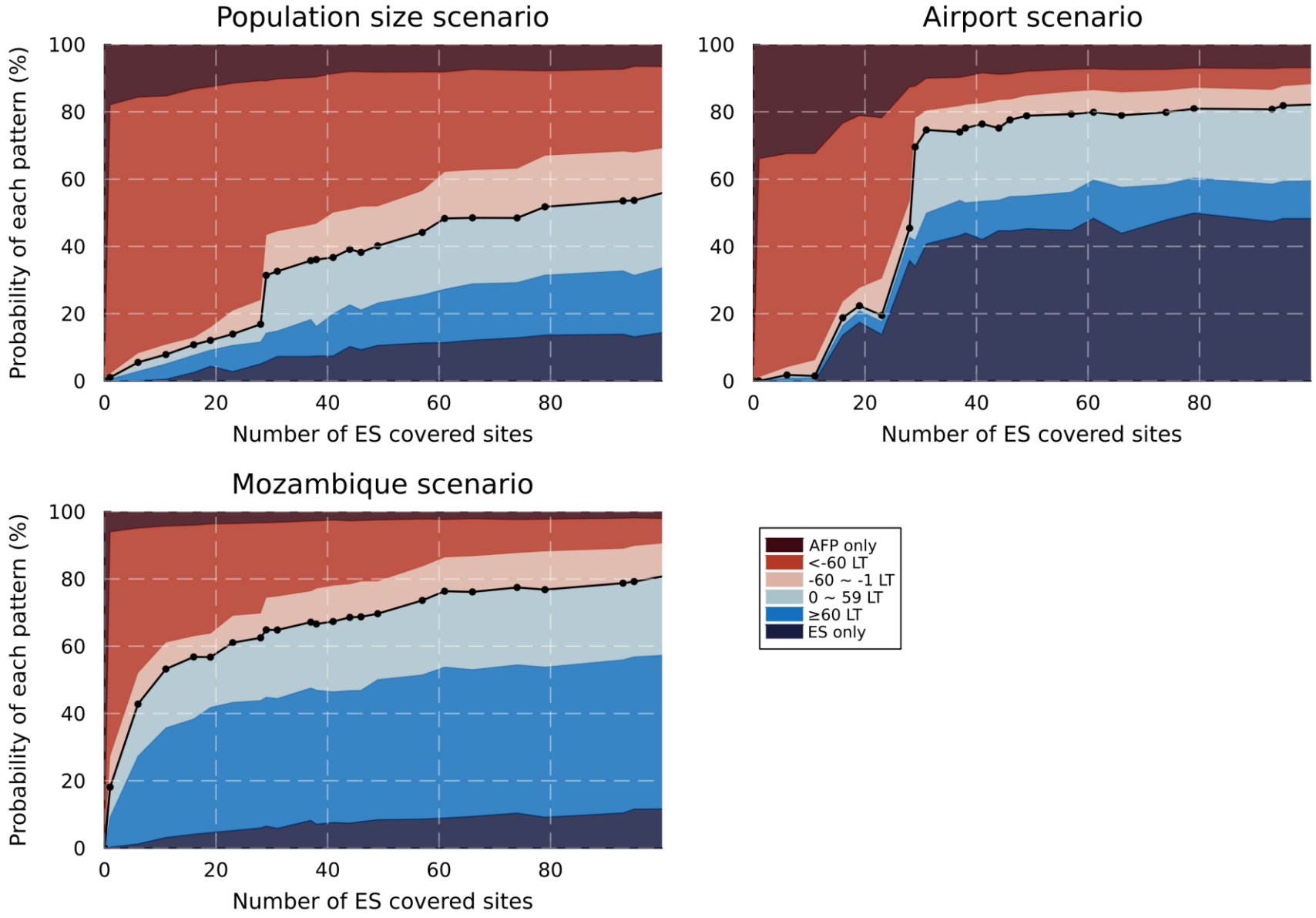
Sensitivity analysis of R0



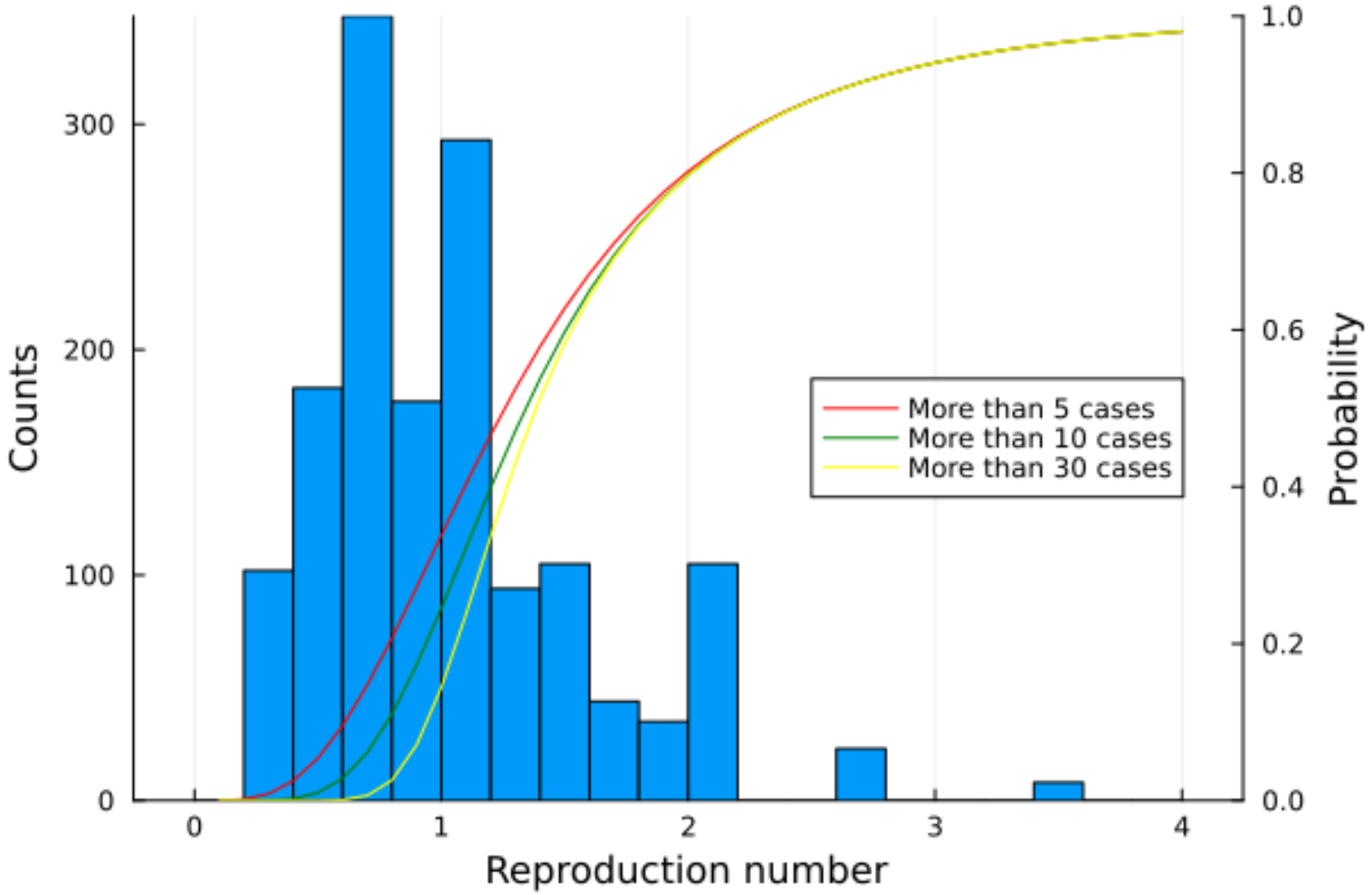
Sensitivity analysis of α



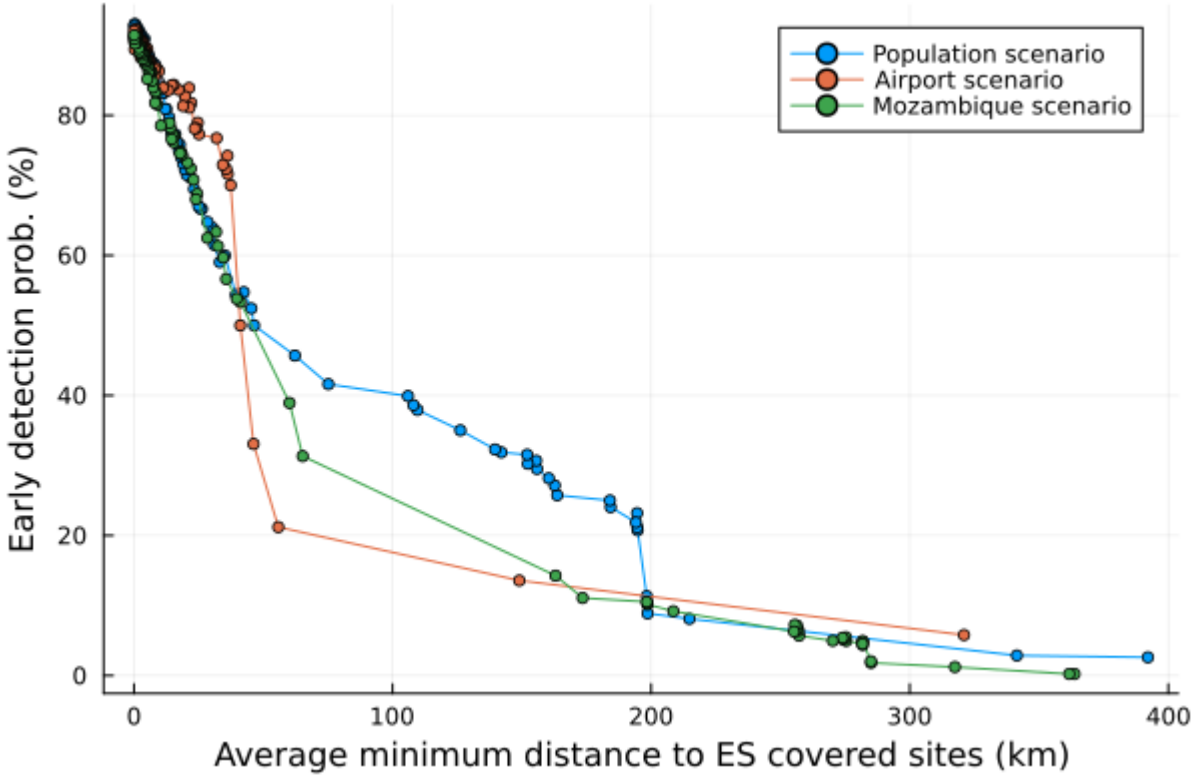
Mozambique importation risk-based ordering

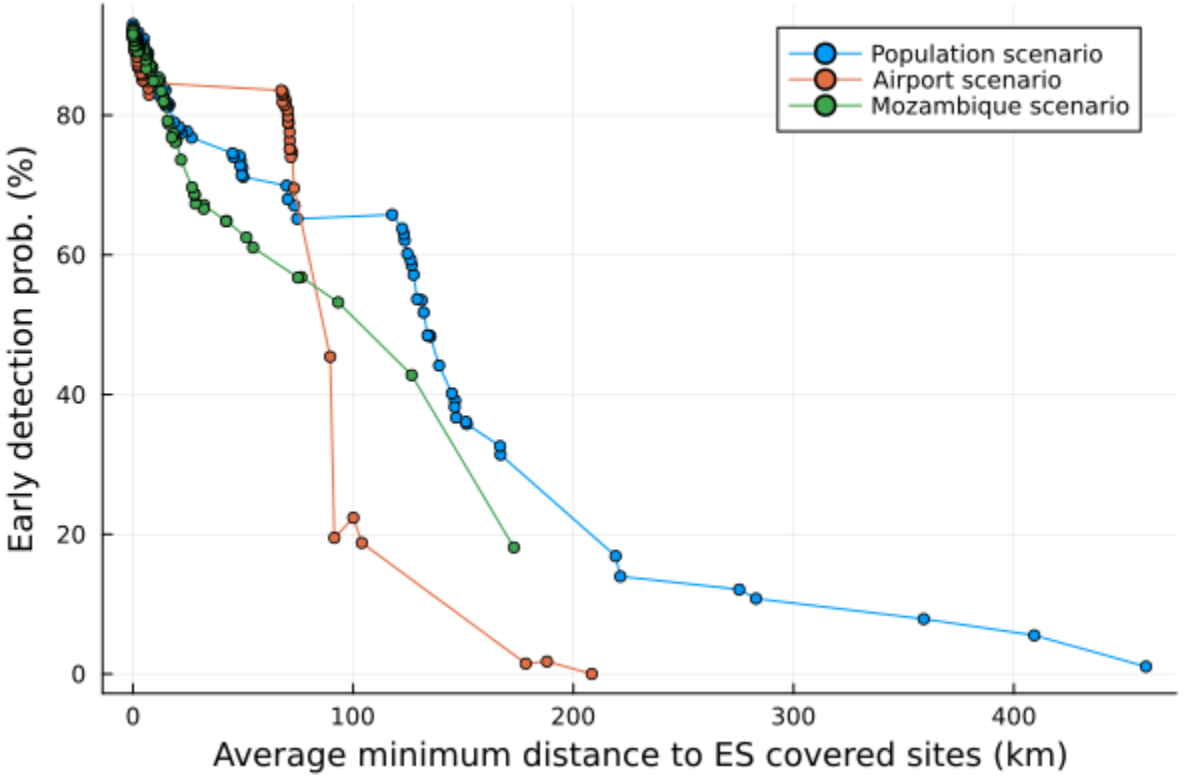


Distribution of $R_e(0)$



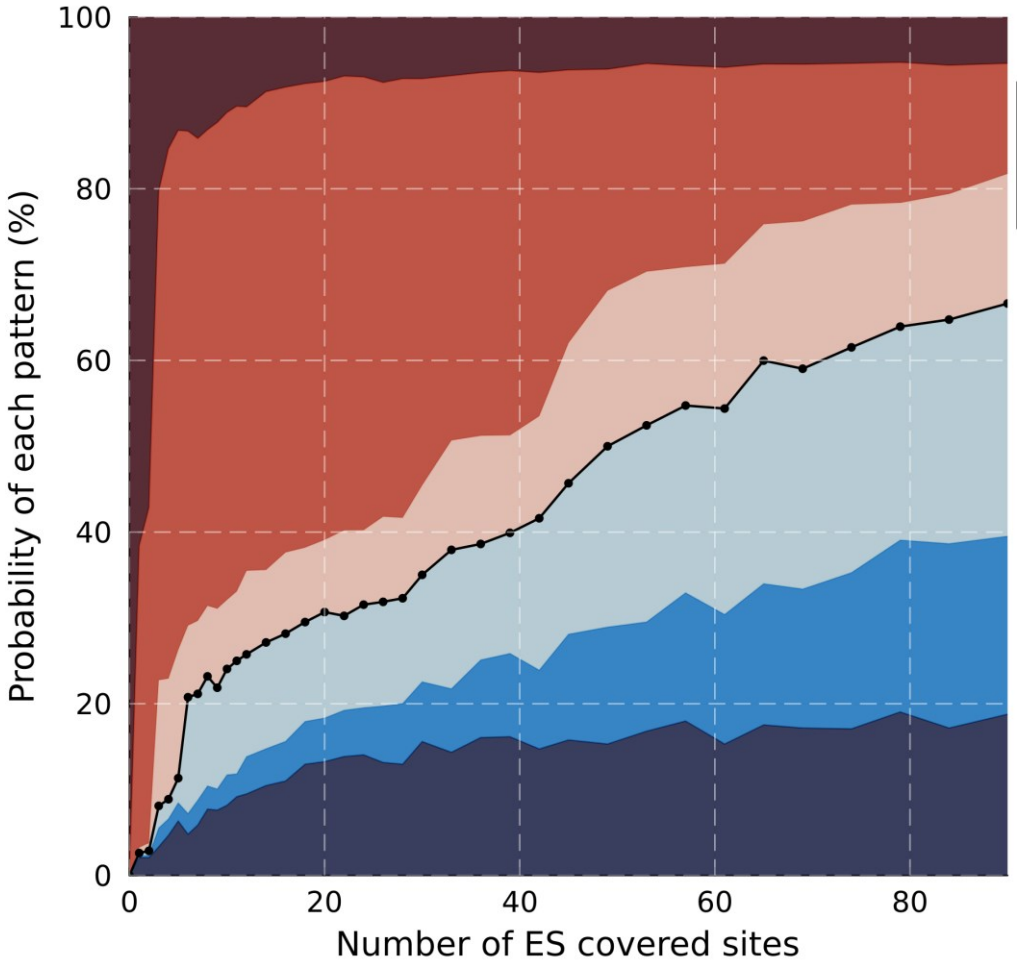
Average weighted minimum distance



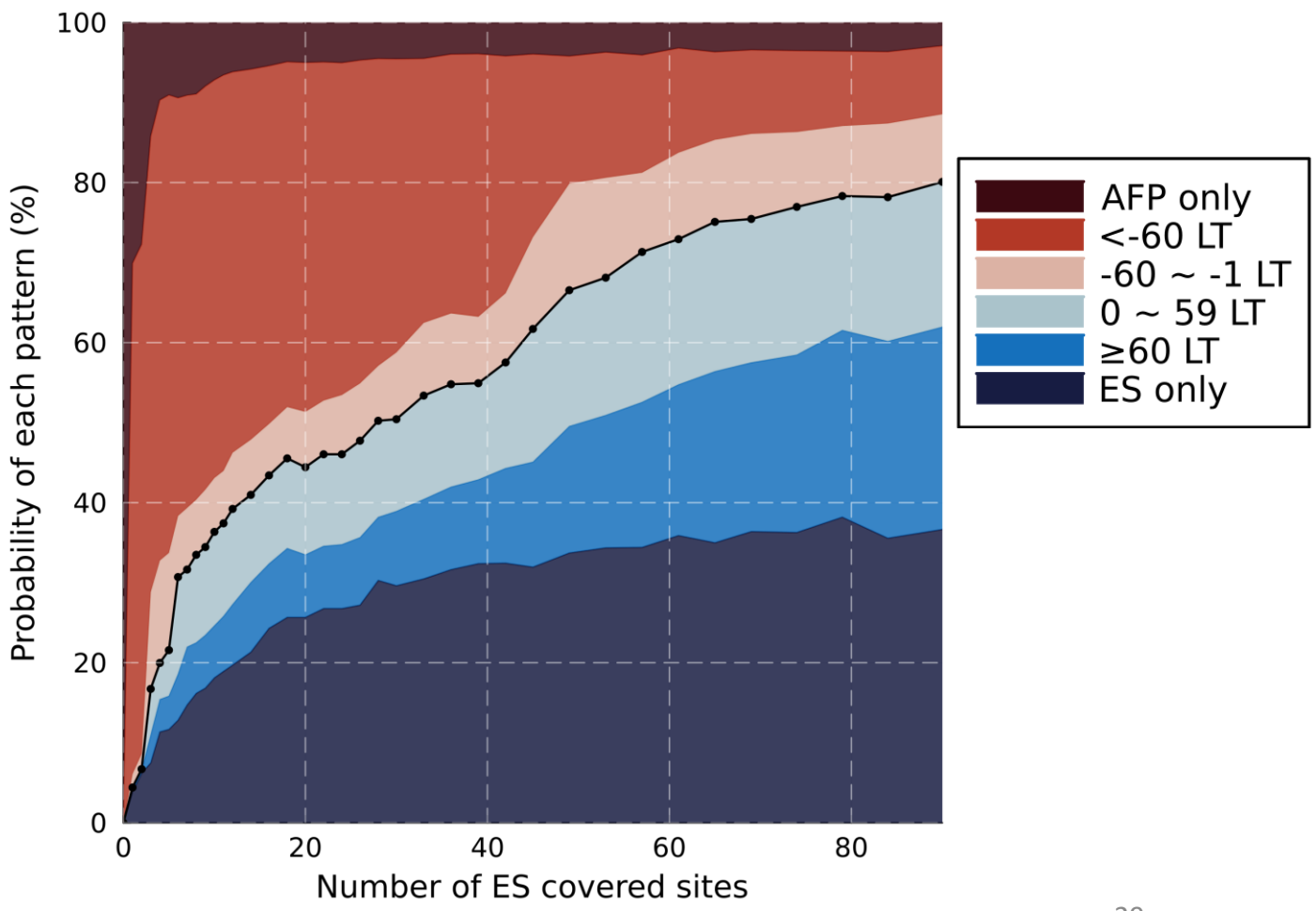


Pc sensitivity

p_c=0.25



p_c=1.0



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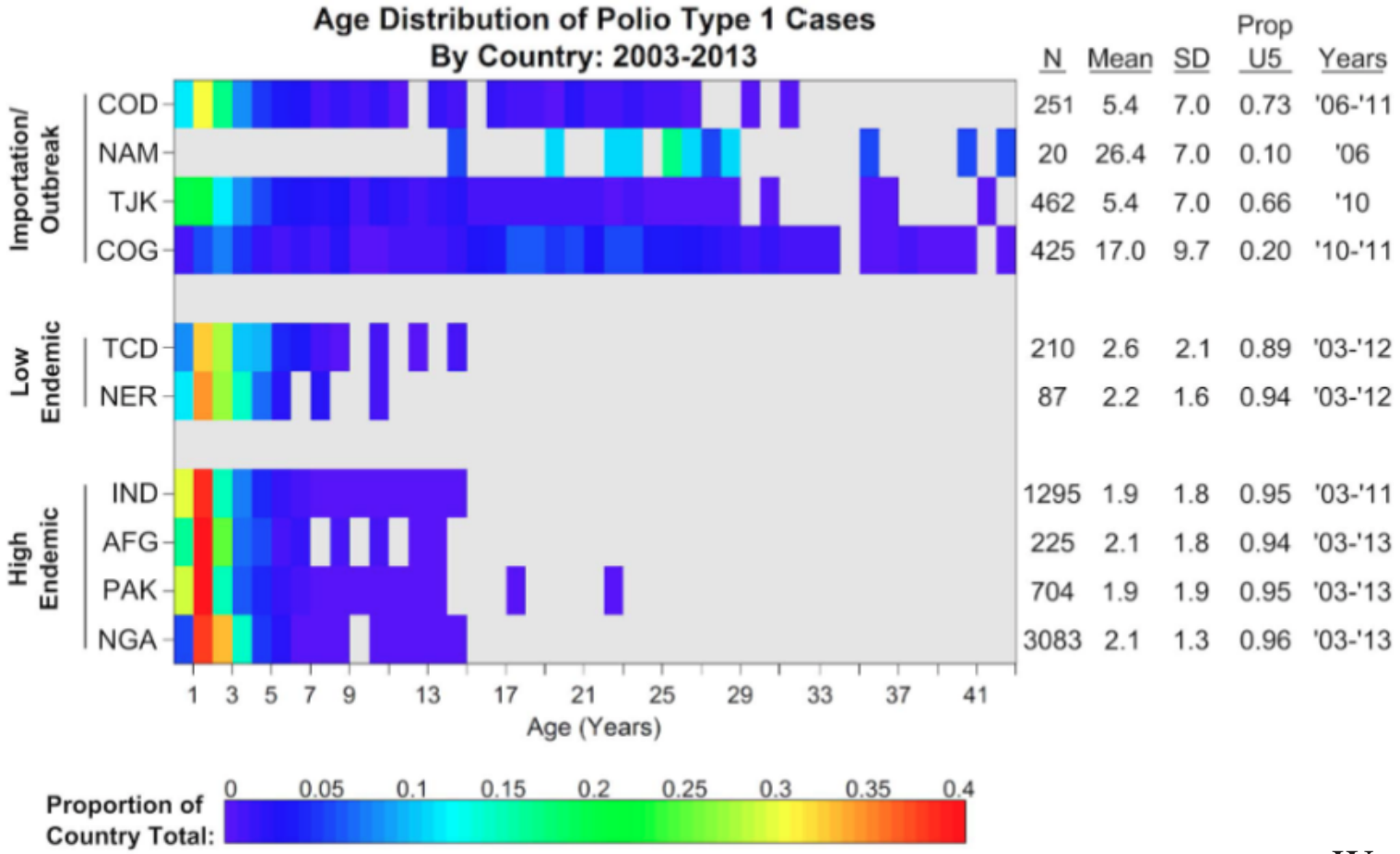

Wagner, Bradley G., et al.
PloS one 9.12 (2014): e113538