Incorporating interventions in your model: evaluating and communicating impact

MATHEMATICAL MODELING FOR INFECTIOUS DISEASE PLANNING IN AFRICA

45 minutes

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Learning objectives

At the end of this lecture, you would:

1. Be able to identify potential issues that may arise when incorporating interventions in your model.

2. Gain skills to develop your model such that these potential issues are averted.

3. Gain skills to effectively summarize model results of intervention impact.

Outline

1. Recap from interventions lecture in session 1

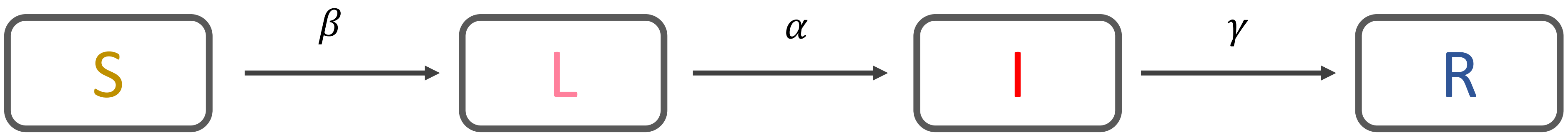
2. Additional considerations for incorporating intervention

3. Summarizing intervention results

Recap

Intervention 1: vaccination

- SLIR model

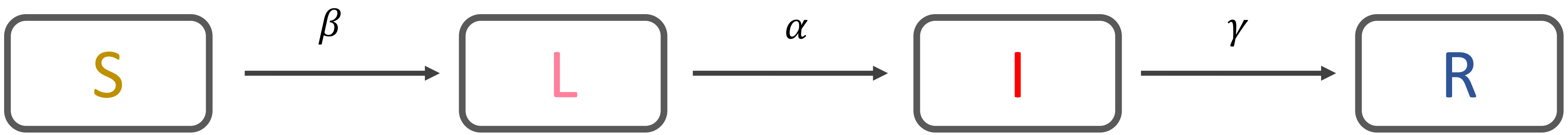


- SLIR model with vaccination (V)

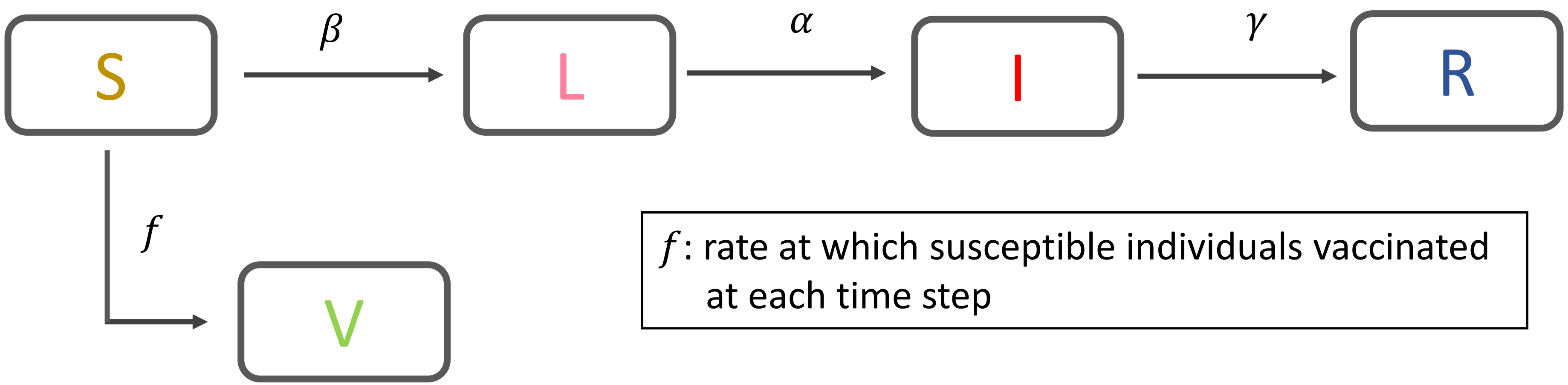
?

Evaluating vaccination effects in SLIR model

- SLIR model



- SLIR model with vaccination (V)



f: rate at which susceptible individuals vaccinated at each time step

Evaluating vaccination effects in SLIR model

- Model equations

$$\frac{dS}{dt} = \frac{-\beta SI}{N} - fS,$$

$$\frac{dV}{dt} = fS,$$

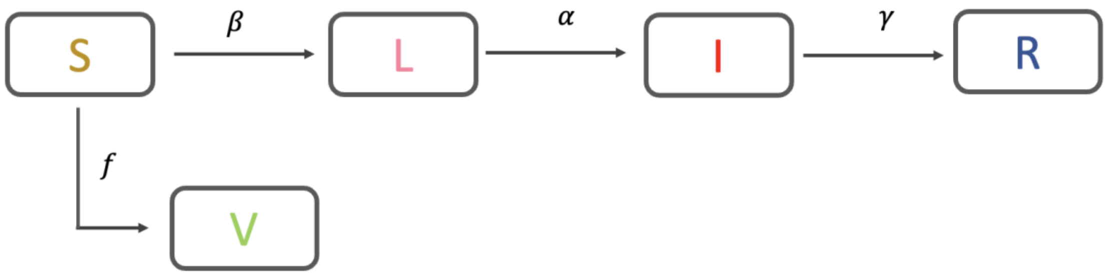
$$\frac{dL}{dt} = \frac{\beta SI}{N} - \alpha L,$$

$$\frac{dI}{dt} = \alpha L - \gamma \mathrm{I},$$

$$\frac{dR}{dt} = \gamma \mathrm{I},$$

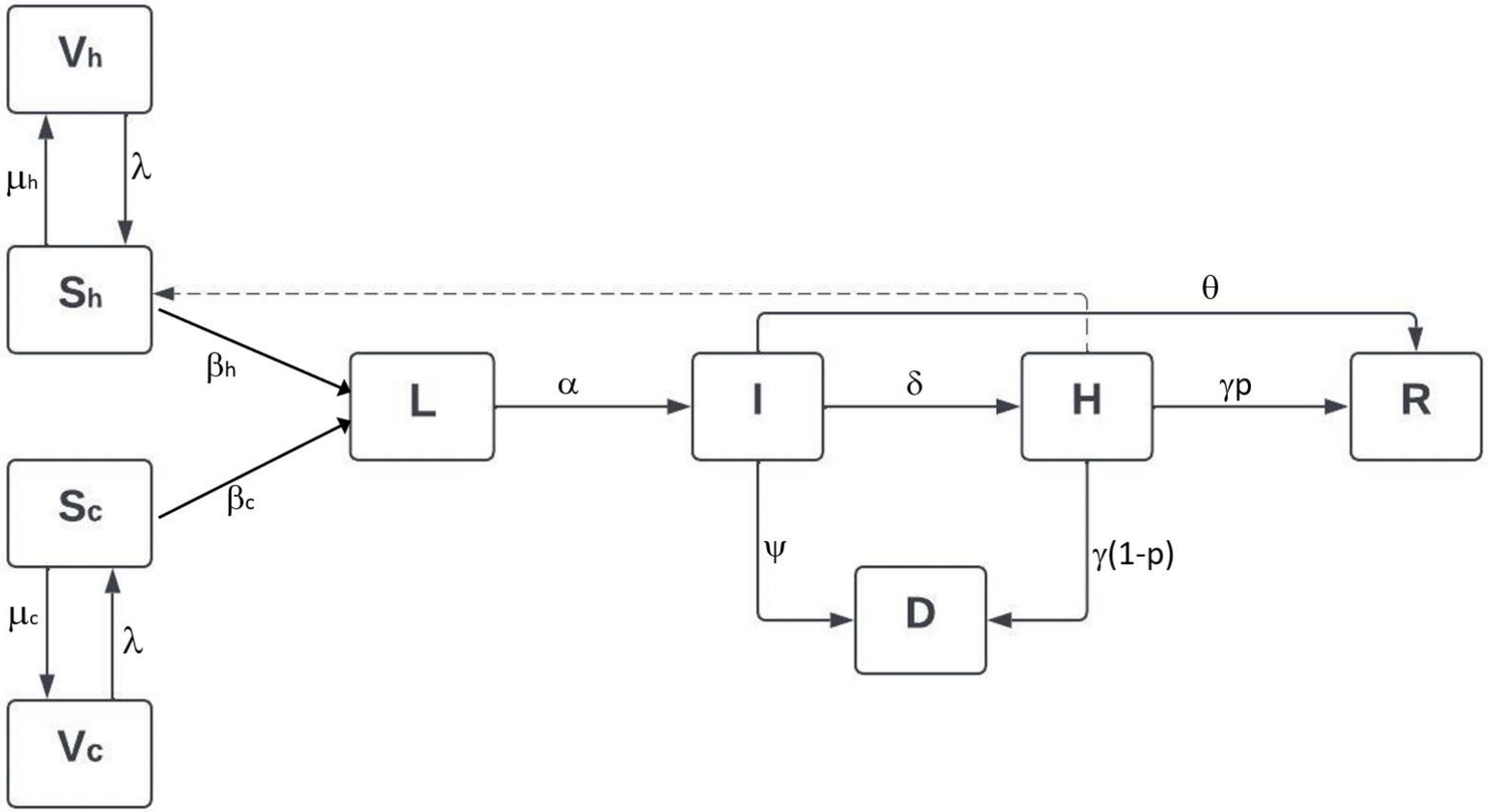
$$N = S + V + L + I + R.$$

f: daily vaccination rate



Intervention 2: Surveillance

Discussion: What is the relevant parameter(s) for assessing the impact of surveillance?

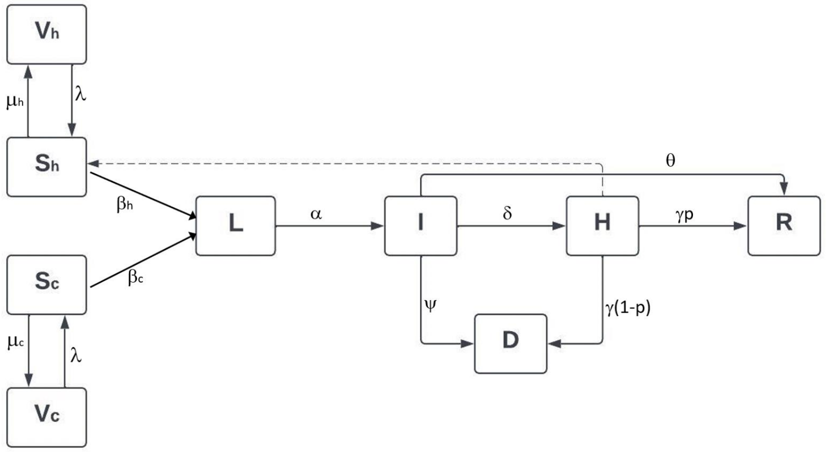


Compartmental diagram for an Ebola transmission model

Credit: Ebola Rwanda team

Relevant parameter: δ, rate at which infectious individuals are detected (and hospitalized)

Intervention 2: Surveillance

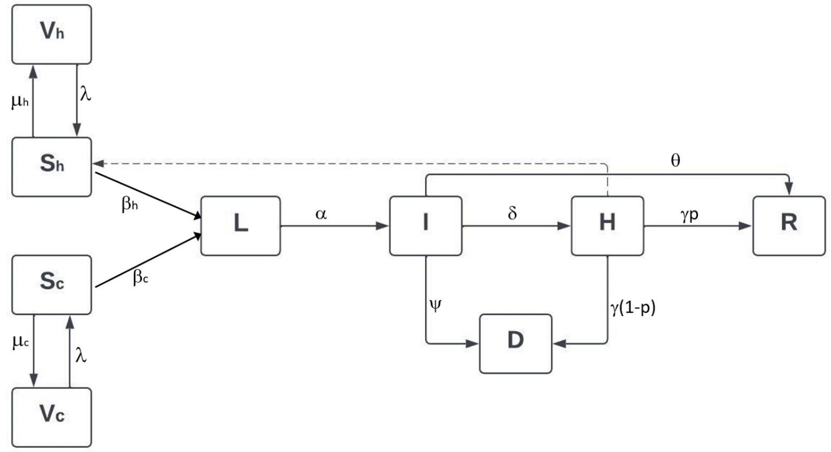


- δ = 1/ average number of days between onset of infectiousness and detection

- Possible values of δ:
  - 1/2 days
  - 1/4 days
  - 1/8 days

- Which of the above values do you think will produce the least incidence (assume all other factors affecting transmission remain constant)?

Evaluating multiple interventions



- Interventions and parameters of relevance
  - Hospitalization;
    - hospitalization rate among infectious individuals: δ
  - Vaccination;
    - vaccination rate among frontliners: μ_h
    - vaccination rate among community: μ_c

- To evaluate impact of hospitalization and vaccination, vary relevant parameters simultaneously and compare outcomes. For example, consider:
  - δ = 0.2 day^{-1}; μ_h= 0.001 day^{-1}
  - δ = 0.2 day^{-1}; μ_h= 0.01 day^{-1}

There are many ways to incorporate interventions.

- **Vaccination?** Including a **compartment** for vaccinated individuals; **assuming** slower progression to infection, compared to unvaccinated
- **Surveillance** (e.g., for Ebola)? Modifying the detection **rate** for infectious individuals
- **Social distancing?** A reduction in contact rates

Depending on the intervention, model modification to account for the intervention may involve changing **rates**, **assumptions** or modifying **compartments**.

Additional considerations to improve realism of interventions

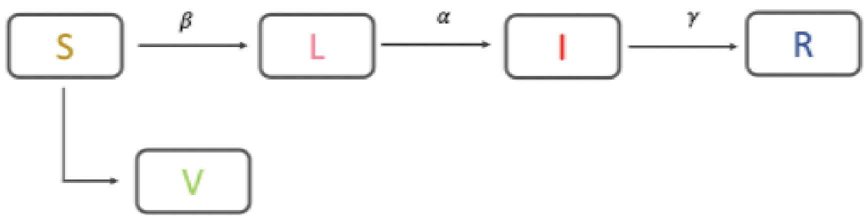
Consideration 1: Are intervention rates realistic?

- Consider vaccination
  - Consider a setting with up to 500 vaccine doses to be distributed in a year (program-specific information)
  - Using a rate of 3.5 doses per day translates to 1278 doses in a year, more than available doses
  - *How does one avoid this potential issue?*
  - Recommendation: Apply absolute numbers instead of rates.

Consideration 1: Are intervention rates realistic?

- For example, 500 vaccine doses administered at a constant rate throughout the year translates to 500/365 ≈ 1.37 doses per day

- One method to incorporate this into model

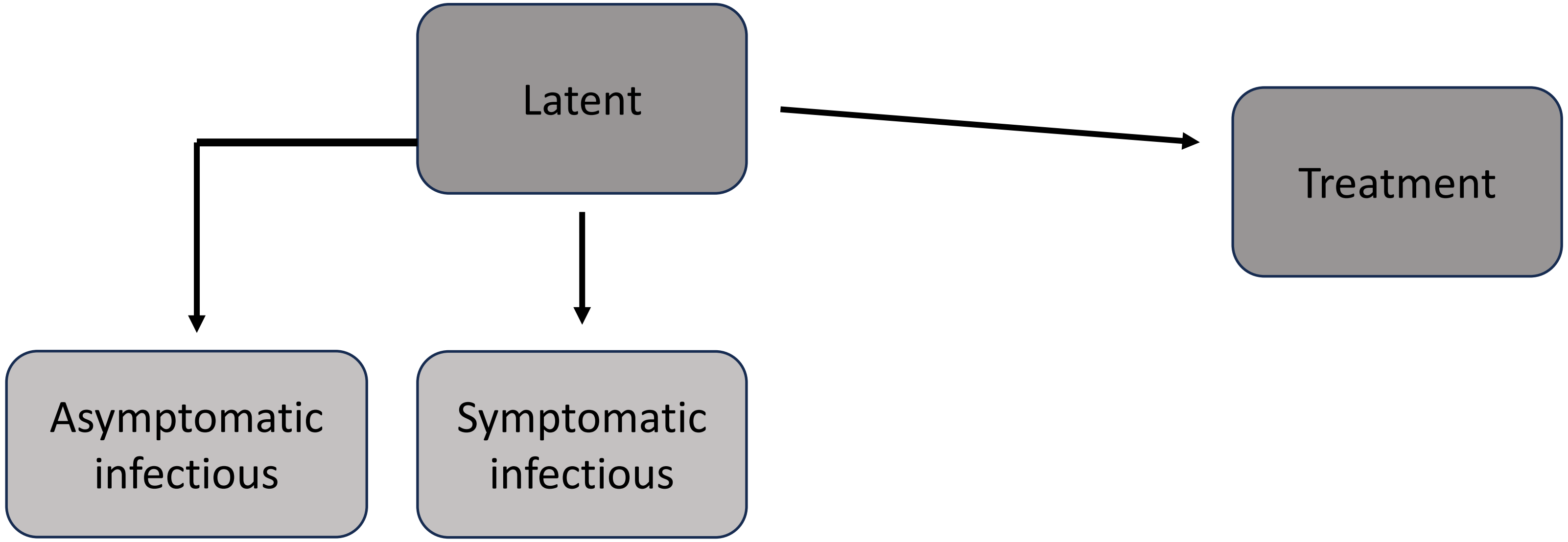


  - Let v = number of doses per day = 1.37
  - Assume
    - only susceptible individuals are vaccinated
    - model runs for a year

  - $\frac{dS}{dt} = \frac{-\beta SI}{N} - v,$

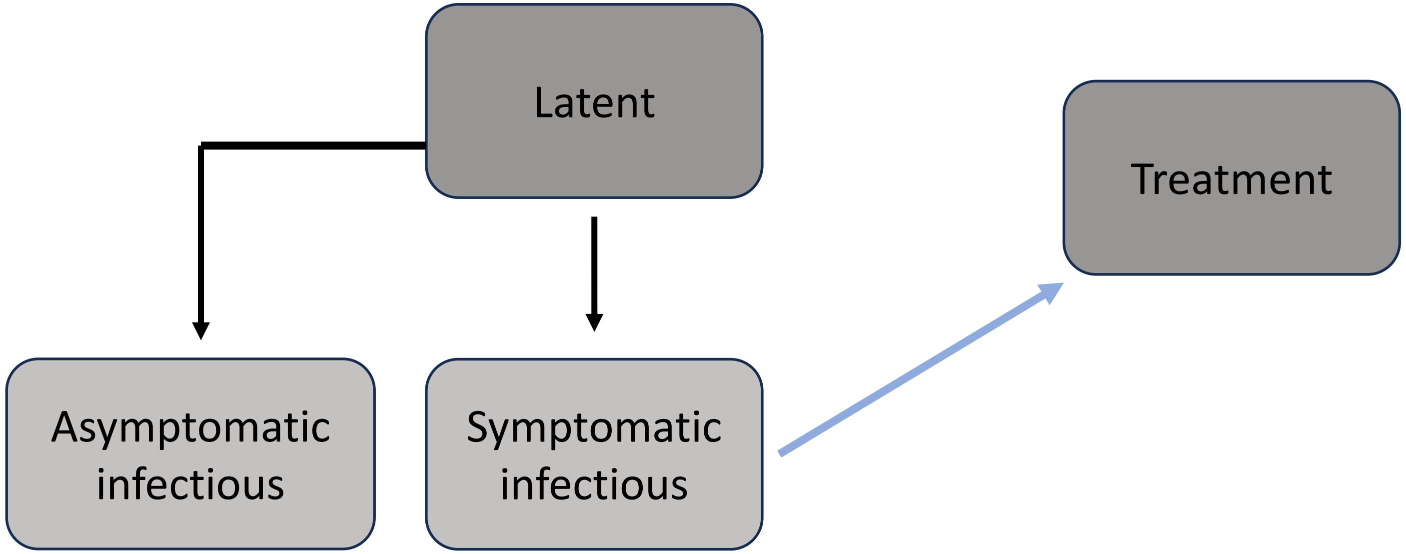
Consideration 2: *When* is the intervention implemented and *who* is directly affected?

- Consider test and treat program for COVID-19 in Rwanda



Consideration 2: *When* is the intervention implemented and *who* is directly affected?

- Consider test and treat program for COVID-19 in Rwanda. If testing is *only* among symptomatic individuals, then we have the following instead.



When: between symptom onset and recovery

Who: Infectious and symptomatic individuals

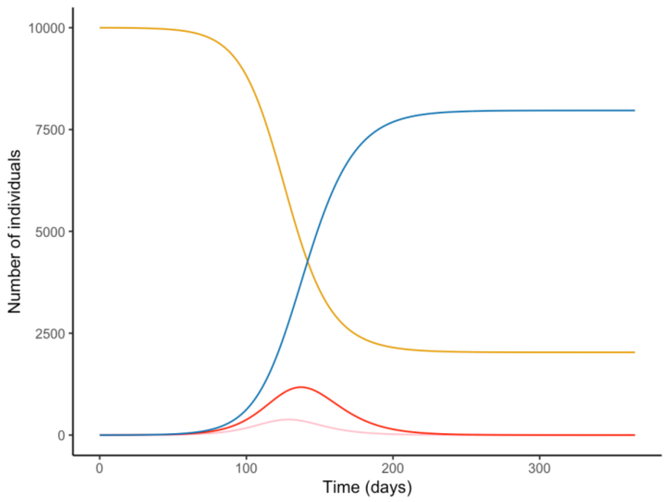
Summarizing intervention results

An example

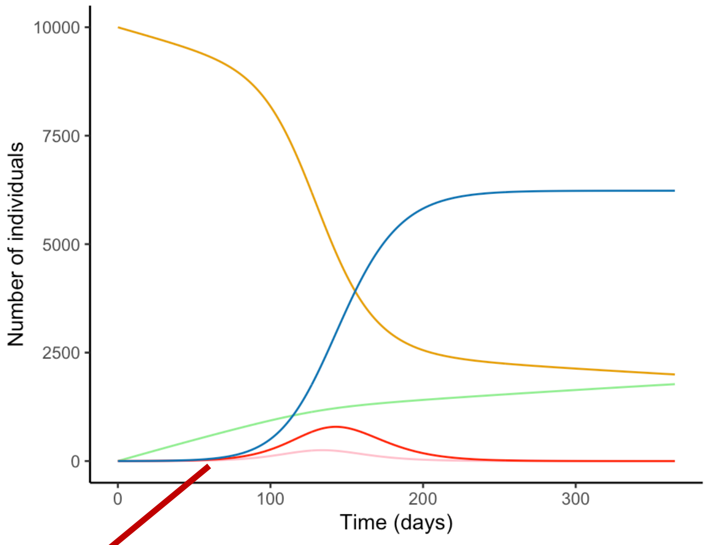
- Clear headings (in figure or in caption)
- Explain parameters (what is f?)

- *What is the impact of increasing vaccination rates?*

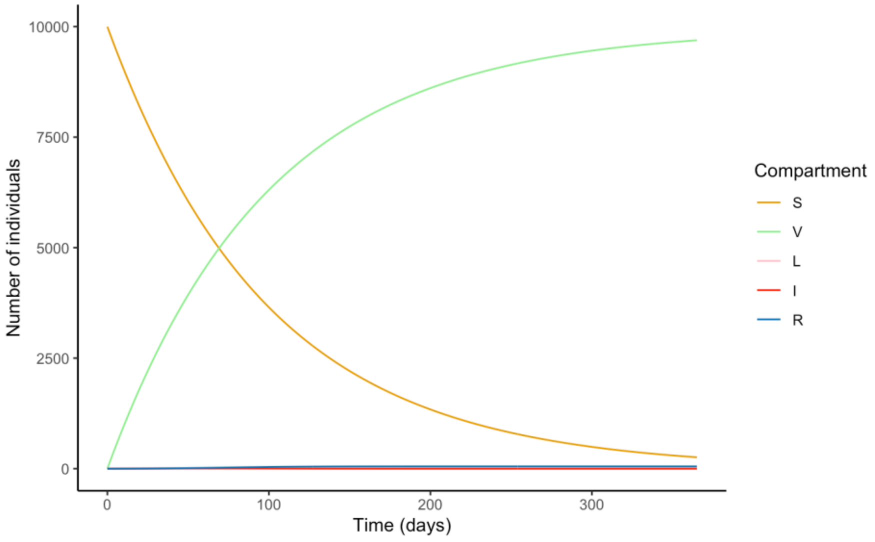
$f = a$



$f = b$



$f = c$



Total # of infections by day 365

x

y

z

Limit curves to those which convey key message(s)

Summarize outcome of interest

Tips for summarizing intervention results

1) Provide clear headings for each figure.

2) Explain all parameter symbols in figure or table captions.

3) Emphasize outcome(s) of interest.

4) Include baseline results to facilitate comparison.

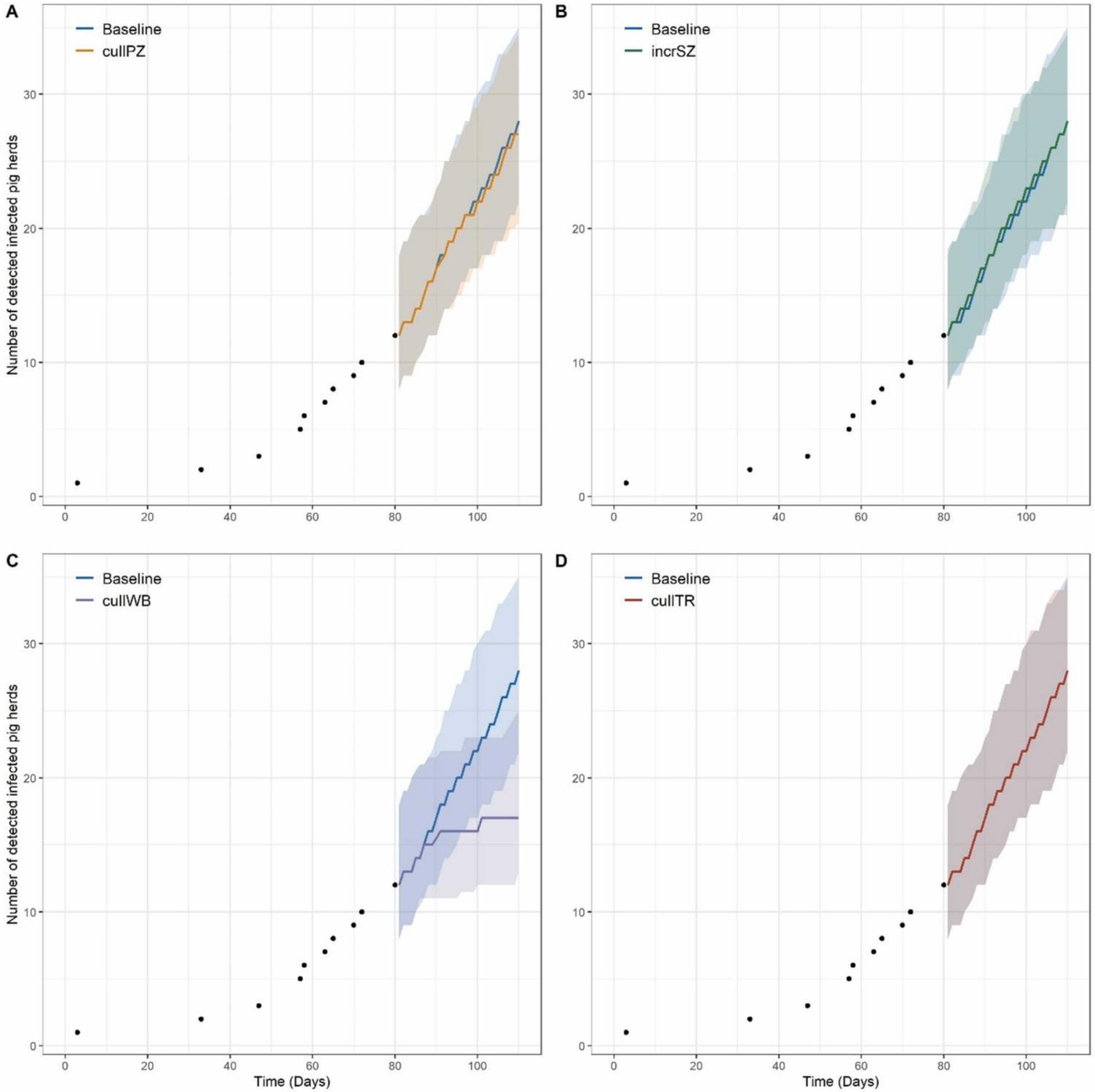
5) For figures, limit curves to those which convey key messages about your outcome(s).

6) For tables, limit contents to those which which convey key messages about your outcome(s)

Simplicity is key.

Example from an African swine fever study (figure)

Caption: Comparison of the impact of additional disease management measures on the number of detected infected pig herds (phase 2). Median model projections are shown along with 95% credible intervals (shaded areas with corresponding colours), for a baseline scenario and four additional disease management measures implemented in pig herds. The baseline scenario ("Baseline") involved regulatory interventions in pig herds and the implementation of fencing and increased hunting pressure in wild boar. The four disease management measures implemented in addition to the baseline scenario are: (1) "cullPZ": culling of all pig herds in protection zones; (2) "incrSZ": increasing the size of the surveillance zone from 10 km (the standard surveillance radius used) to 15 km; (3) "cullWB": culling of all pig herds located at less than 3 km from positive wild boar; (4) "cullTR": culling of all herds that have traded pigs with an infected farm less than three weeks before detection.



Dankwa, E.A. *et al.* (2022) 'Stochastic modelling of African swine fever in wild boar and domestic pigs: Epidemic forecasting and comparison of disease management strategies', *Epidemics*, 40, p. 100622.

Example from an African swine fever study (table)

Model fit and projections for the cumulative number of detected infections under the two main disease management scenarios considered in wild boar: increased hunting pressure and normal hunting pressure. The model fits are median model estimates for the observed period (days 1–50 for phase 1, days 1–80 for phase 2 and days 1–110 for phase 3) while the model projections are median model estimates for the unobserved periods over which projections were computed (days 51–78 for phase 1, days 81–110 for phase 2, days 111–230 for phase 3). Model estimates are medians of 500 simulations along with 95% credible intervals (CrI) in parentheses.

Phase	By day	Disease management scenario[a]	Wild boar			Pig herd		
			Observed	Model fit (95% CrI)	Model projections (95% CrI)	Observed	Model fit (95% CrI)	Model projections (95% CrI)
1	50		397	396 (358–435)		3	4 (2–6)	
	78	Increased hunting pressure			1770 (1445–2503)			8 (5–14)
		Normal hunting pressure			933 (751–1289)			8 (5–14)
2	80		2007	2009 (1912–2102)		12	12 (8–17)	
	110	Increased hunting pressure			3214 (3112–3378)			28 (22–35)
		Normal hunting pressure			3272 (2973–3868)			30 (23–38)
3	110		2984	2994 (2897–3077)		26	25 (21–31)	
	140	Increased hunting pressure			3442 (3372–3514)			38 (32–48)
		Normal hunting pressure			7954 (6891–8827)			87 (67–100)
	230	Increased hunting pressure			4599 (4480–4711)			113 (99–129)

[a] For all phases, scenarios are only indicated for projected periods and not for observed periods. For the observed periods, the scenario for phase 1 is normal hunting pressure with no fence whereas the scenario for phases 2 and 3 is increased hunting pressure.

Activity

- Apply considerations and intervention summary tips discussed to your model