Improving estimates of epidemiological quantities with wastewater data in Aotearoa New Zealand

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This project is a collaboration between the University of Oxford (UK), the University of Canterbury (NZ), and the Institute of Environmental Science and Research (NZ).

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Motivation

- The reproduction number R_t is typically estimated using reported cases
- Tracking wastewater concentrations of viral material has been proposed as an alternative source of data
- Can we use both simultaneously?

The Institute of Environmental Sciences and Research New Zealand collected wastewater sampling data throughout the COVID-19 pandemic [1]. Figure 1 (below) shows reported cases and wastewater sampling data between Jan 2022 and Mar 2023.

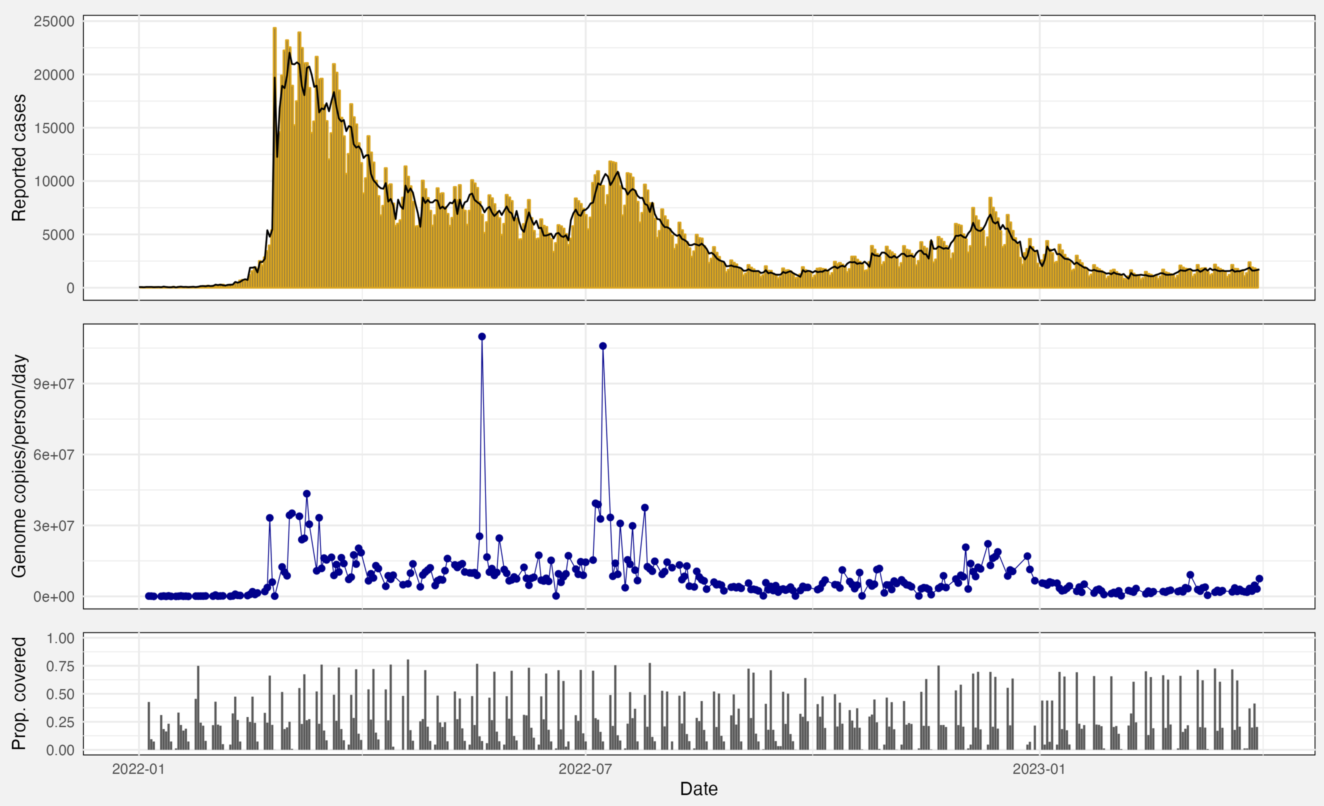


Figure 1: National data from Aotearoa New Zealand. Daily reported COVID-19 cases (orange bars), detrended cases (black line), SARS-CoV-2 concentration in wastewater (blue line and dots), and proportion of population covered by sampled wastewater catchments (gray bars).

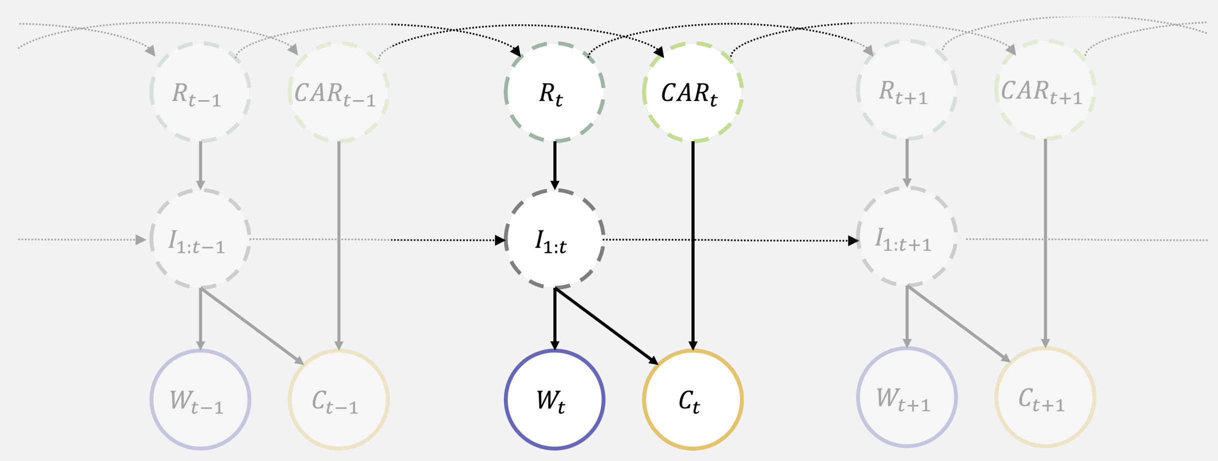
The model...

...is a hidden-state model that relates **observed data:**

- Reported cases C_t
- Wastewater samples W_t

to **unobserved states:**

- Reproduction number R_t
- Case ascertainment ratio CAR_t
- Infection incidence I_t



We let R_t and CAR_t vary smoothly over time, and let I_t follow a Poisson renewal model:

$$R_t \sim \text{Normal}(R_{t-1}, \sigma_R R_{t-1})$$

$$CAR_t \sim \text{Normal}(CAR_{t-1}, \sigma_{CAR})$$

$$I_t \sim \text{Poisson}(R_t \sum I_{t-u} g_u)$$

C_t is modelled using a negative binomial distribution and W_t using a Gamma distribution with expected values:

$$E[C_t] = CAR_t \sum I_{t-u} L_u$$

$$E[W_t] = \alpha \sum I_{t-u} \omega_u$$

g_u, L_u, and ω_u are the generation interval, case reporting delay, and wastewater shedding distributions respectively. α is the average total detectable viral material shed by an infected person.

References

[1] Joanne Hewitt et al. Sensitivity of wastewater-based epidemiology for detection of SARS-CoV-2 RNA in a low prevalence setting. *Water Research*, 211:118032, March 2022.

[2] Leighton M. Watson et al. Improving estimates of epidemiological quantities by combining reported cases with wastewater data: A statistical framework with applications to COVID-19 in Aotearoa New Zealand. *medRxiv preprint*, August 2023.

Results

We solve for R_t, CAR_t, and I_t using a particle filter with fixed lag resampling. The particle marginal Metropolis Hastings algorithm is used to fit model parameters. The final output is a collection of samples from the posterior distributions of our unobserved states at each time-step given our observed data $P(R_t, CAR_t, I_t | C_{1:T}, W_{1:T})$. These are presented in Figure 2:

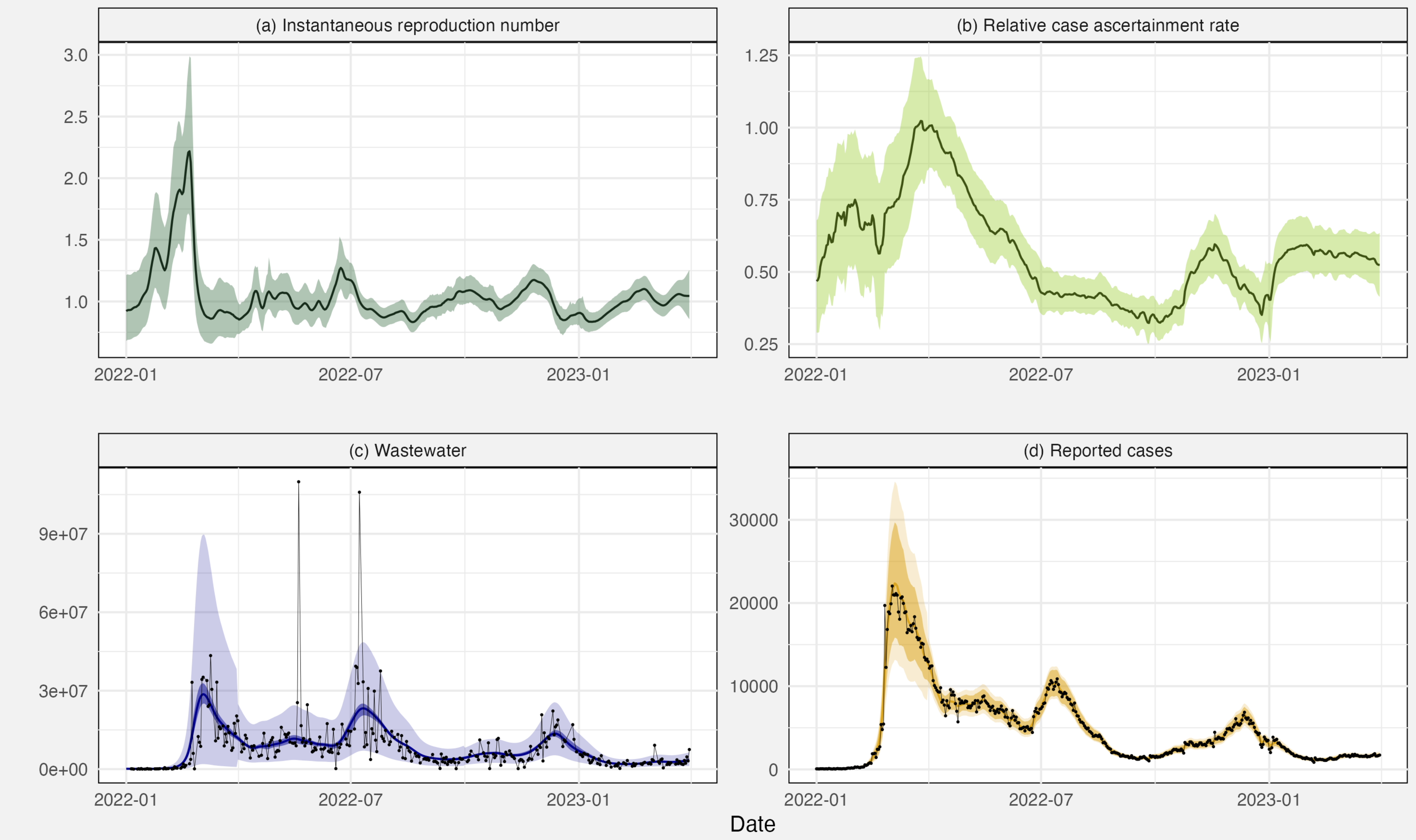


Figure 2: Estimated epidemiological quantities for SARS-CoV-2 in Aotearoa New Zealand. Shaded regions show 95% credible intervals. Lighter shading in panels (c) and (d) shows 95% predictive intervals (accounting for observation noise). Black dots and lines show observed data. CAR_t is reported relative to 1 April 2022, assuming α is constant.

Wastewater versus reported cases (work in progress)

- Wastewater sampling data are very noisy, so may we expect them to be less informative about R_t than reported cases.
- However, models based solely on reported cases assume that CAR_t is constant!
- What happens if we allow CAR_t to vary in a cases-only model?
- We can answer this by solving our model using only one source of data at a time.

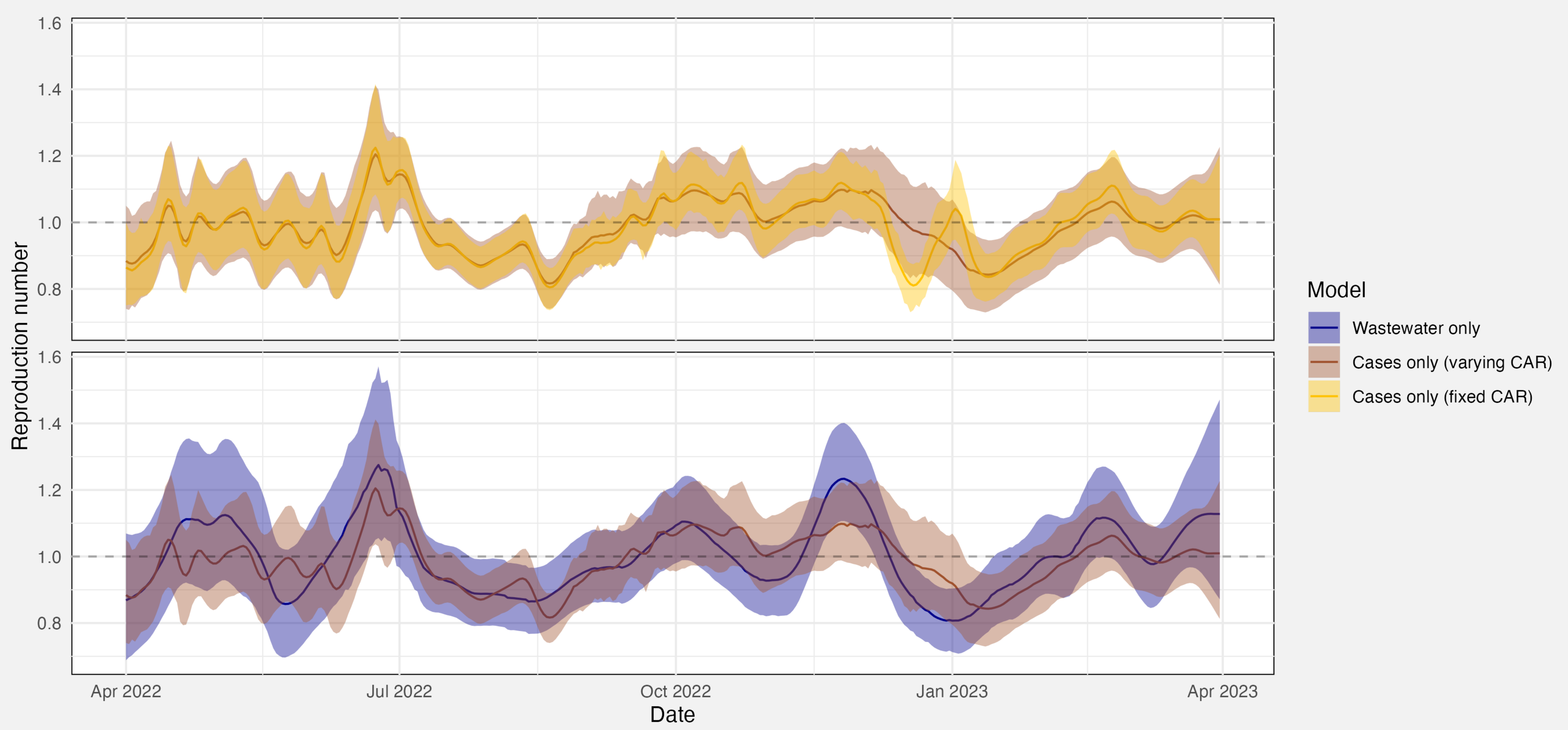


Figure 3: Estimates of R_t from wastewater data only, reported cases only with a variable CAR_t, and reported cases only with a fixed CAR_t. Shaded regions show 95% credible intervals. For presentation purposes, we show results between April 2022 and March 2023.

- Uncertainty in R_t (when fit to reported cases alone) is higher when we allow CAR_t to vary, than when we assume CAR_t is constant.
- In both scenarios, wastewater data appear to be less informative about R_t than reported cases. Particularly when we assume CAR_t is constant.
- This difference is less clear when CAR_t is allowed to vary.
- **As testing (or consistency in testing) decreases, wastewater could plausibly become the more informative source of data (with respect to R_t).**

In this work, we assume the **detectable viral material shedding rate** α is fixed. We have just kicked the can down the road!

Future work: can we use epidemic surveys, like REACT-1 in England, to quantify how α varies over time?