Technical report: update to modelling 7 September 2021

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7 September 2021

Summary

- **It is highly likely that the R number was less than 1 between 23 August and 4 September, which means cases are decreasing.**
- It is uncertain exactly how much R is less than 1. This is important because it makes a large difference to the length of time needed to eliminate the outbreak.
- Fitting the model to data up to 4 September, the central estimate for R_{eff} is 0.4 with a 95% CrI (0.2, 0.6).
- **NB there are important caveats to this estimate:**
    - The estimates are subject to modelling assumptions, which will not all be correct.
    - The model assumes that there are no large undetected clusters currently in the community.
    - The model assumes that the effect of Alert Level 4 restrictions on transmission is constant in the period from 23 August onwards whereas in reality a range of factors could cause R_{eff} to change over time.
    - It is difficult to precisely estimate R with small case numbers.

Summary of Methods

A modified version of the age-structured stochastic branching process model for COVID-19 transmission with vaccination was implemented [1]. The proportion of each age group that has received one or two doses of the vaccine is time-varying based on vaccinations already administered, as well as data on future bookings. Population age structure and vaccination coverage are based on data from the Auckland metro region. Vaccine effectiveness parameters are as in Steyn et al (2021), with the additional assumption that one dose of the vaccine provides 23% protection against infection (relative to 70% protection after two doses).

Outbreaks are seeded by introducing 135 cases uniformly distributed between 10 August and 17 August. The model begins on 10 August with $R_0 = 6.0$, which implies a median of 385 infections at detection, including those infected on August 17. This should be considered a model input, not an estimate of the size at detection.

We assume that the probability of case detection for all infected individuals (clinical and subclinical) after August 17 is 80%, and detection occurs with an exponentially distributed delay from onset (or pseudo-onset for subclinical individuals) with mean 4 days. In reality, some close contacts are scheduled for testing on day 5 and day 12 after exposure; however we do not attempt to model the contact tracing process at this level of detail. The shape of the distribution is consistent with onset to reporting times from the August 2020 outbreak. All

cases are assumed to be immediately isolated on detection with no further transmission. The estimated reduction in R_{eff} from these measures is 16.5%.

Given the lag from infection to testing, the effect of Alert Level 4 (AL4) on reported case numbers will not be seen until around 7-10 days after restrictions were introduced. Until then, it is uncertain what the effective reproduction number under the current Alert Level 4 restrictions may be. In April 2020, during an outbreak caused by multiple introductions of the wildtype variant of SARS-CoV-2, we estimated R_{eff} to be between 0.4 and 0.6 during AL4. However, in New South Wales, a current lockdown is struggling to contain their outbreak, with R_{eff} above 1. Thus, a range of values for R_{eff} under AL4 are conceivable.

For simplicity, we assume that vaccination, case isolation, and alert level restrictions act independently to provide multiplicative reductions in R_{eff}. Under the model assumptions described above, vaccination at the 17 August coverage level reduces R_{eff} by around 13% (from $R_0 = 6$ to $R_v = 5.0$). After the outbreak is detected, the effects of case isolation and contact tracing reduce R_{eff} by a further 16.5% to $R_c = 4.2$. We assume that Alert Level 4 reduces the effective reproduction number to R_{AL4}. This is modelled as a relative reduction in transmission of R_{AL4}/R_c due to Alert Level 4 restrictions. We assume that, rather than a step change, the effect of Alert Level 4 reductions is to decrease transmission linearly over a period of 5 days starting on 17 August. Therefore the relative effect of Alert Level 4 restrictions on transmission at time t is characterised by $C(t) = 1 - \phi(t)(1 - R_{AL4}/R_c)$, where $\phi(t)$ is equal to 0 before 18 August, equal to 1 from 23 August onwards, and linearly increases from 0 to 1 between these dates. This 5-day transition period models a gradual reduction in transmission due to Alert Level restrictions and could include effects such as saturation of household transmission and people travelling home after the lockdown was announced. The ongoing vaccination programme continues to reduce the effective reproduction number over time; R_{AL4} should be interpreted as the effective reproduction number under Alert Level 4 restrictions and at 17 August vaccine coverage levels.

We treat R_{AL4} as a fixed but unknown model parameter and treat it as a target for parameter inference. We use approximate Bayesian computation (ABC) to estimate the posterior distribution for R_{AL4}, using a uniform prior on (0, 2). The mean square error is used as a summary statistic to quantify the difference between the output of a given realisation of the stochastic model and the reported daily case data between 17 August and a cut-off date of 4 September, using the *Date reported* field in EpiSurv. The posterior distribution for R_{AL4} is approximated using an ABC rejection algorithm, retaining a proportion $\alpha = 0.01$ of $N = 100{,}000$ model simulations with the smallest mean square error. Projected case numbers are based on these retained model simulations.

Results

Figure 1 shows the modelled number of reported daily cases, fitted to data up to the cut-off date specified in Methods, and conditional on all other modelling assumptions. Figure 2 shows the modelled cumulative cases until 1 November. Figure 3 shows the posterior distribution of R_{AL4}. The posterior distribution has a mean of 0.37, 95% CrI (0.18, 0.56) and a greater than 99% probability that $R_{AL4} < 1$.

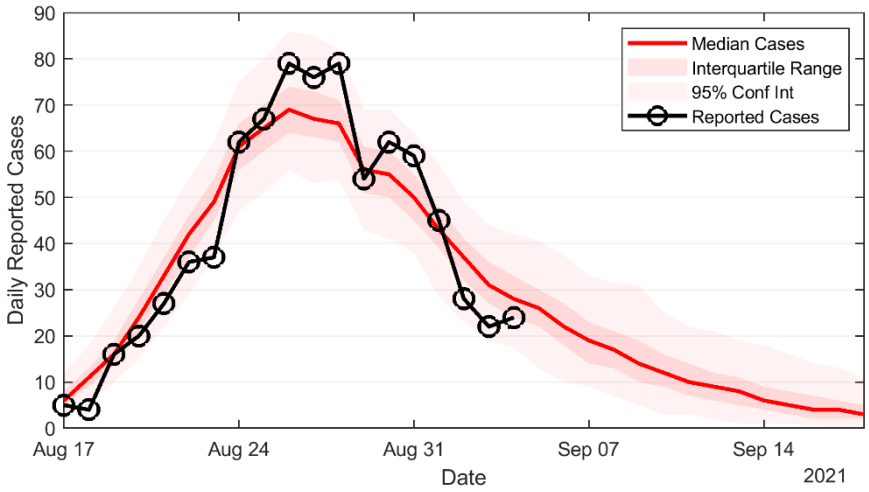

Figure 1. Number of reported daily cases (open circles) and the median, 50% prediction interval and 95% prediction interval of the retained simulations ($\alpha = 0.01$). The model is fitted to reported daily case data indicated by black open circles. Note: reported daily case data covers the period from midnight to midnight each day and differs from the number of cases reported in the Ministry of Health's 1pm media releases.

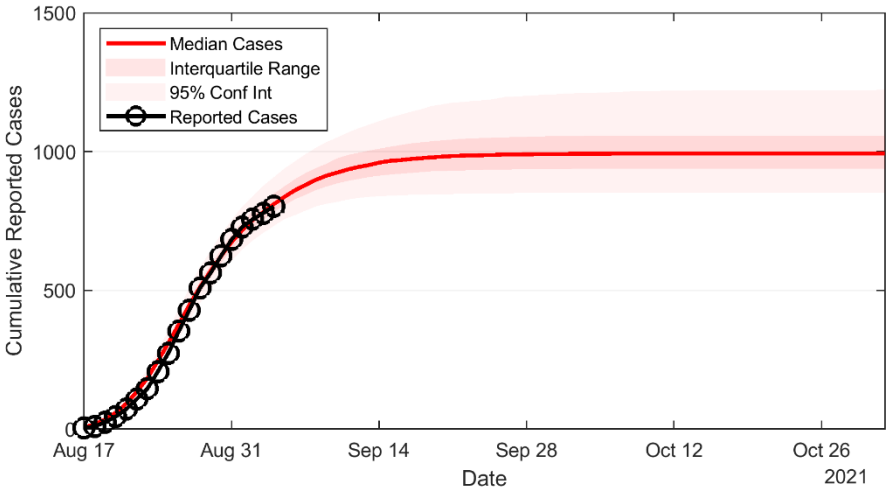

Figure 2. Cumulative reported cases (open circles) and the median, 50% prediction interval and 95% prediction interval of the retained model simulation ($\alpha = 0.01$). Final outbreak size is highly sensitive to all assumptions, so the true confidence intervals are likely to be wider than plotted.

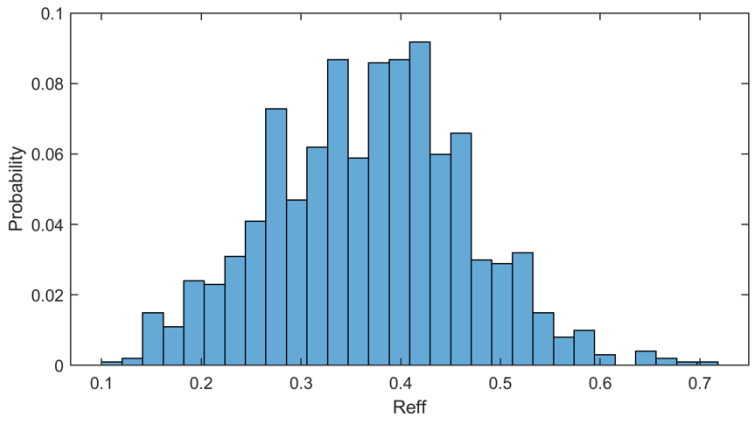

Figure 3. The estimated posterior distribution of R_{AL4} for the period of time after 23 August, conditional on all other assumptions and fitted to data on daily reported cases up to the cut-off date stated in the text.

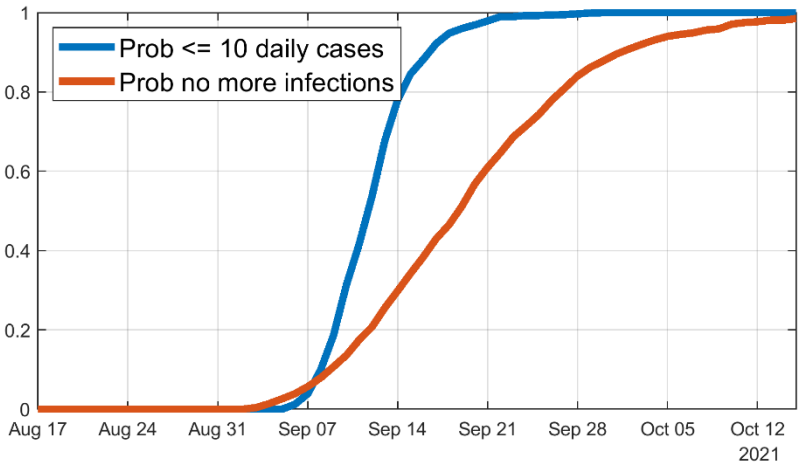

Figure 4. The proportion of retained model simulations in which there are less than or equal to 10 reported cases on any given day for the rest of the outbreak (blue), and the proportion of simulations in which no more infections occur (red), after the given date. These results assume that the effect of Alert Level 4 restrictions on transmission remains constant until the outbreak is eliminated. Note: it is possible in the model to have no further infections after a given date but to still have more than 10 cases reported on a single day because of the lag from infection to reporting.

Key model sensitivities

The posterior distribution for R_{AL4} assumes that all other parameters are fixed and correct. This is likely incorrect and must be considered when interpreting these results. Table 1 outlines some key assumptions that may influence the estimates of R_{AL4}.

Parameter	Assumed Value	Discussion
Number of seed cases/outbreak size at detection	Assumed to be 135 seed cases, which implies a cumulative total of around 380 people infected when the outbreak was first detected	If there were fewer cases at detection, then all else held equal, the estimates of R_{AL4} would likely be higher (so that reported cases are at the same level).
Time period over which reduction in transmission due to Alert Level 4 restrictions takes place	5 days	If it takes longer for the full effect of Alert Level 4 on transmission to take effect (e.g. as household transmission saturates), the observed R_{AL4} could continue to decline below the values estimated here.
Proportion of infections that are detected	80%	We assume there are no large undetected clusters. If there is undetected spread in essential workplaces for example, then the proportion of recent cases being detected may be lower and our results for R_{AL4} may be underestimates.

Parameter	Value
Basic reproduction number in the absence of control	$R_0 = 6$
Incubation period	Mean 5.5 days, s.d. 3.3 days
Generation interval	Mean 5.0 days, s.d. 1.9 days
Relative infectiousness of subclinical individuals	$\tau = 0.5$
Heterogeneity in individual reproduction number	$k = 0.5$
Vaccine effectiveness:	
- against infection (one dose)	$e_{I,1} = 0.23$
- against infection (two doses)	$e_{I,2} = 0.7$
- against transmission in breakthrough infection (two doses)	$e_T = 0.5$
Probability of a community case being tested	$p_{test,outbreak} = 0.8$
Mean time from symptom onset to test result	4 days

Age-specific parameters

Age (yrs)	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75+
Pr(clinical) (%)	54.4	55.5	57.7	59.9	62.0	64.0	65.9	67.7	69.5	71.2	72.7	74.2	75.5	76.8	78.0	80.1
Susceptibility*	0.46	0.46	0.45	0.56	0.80	0.93	0.97	0.98	0.94	0.93	0.94	0.97	1.00	0.98	0.90	0.86
% of popn**	6.2	6.6	6.5	6.3	7.3	8.5	8.3	7.5	6.5	6.6	6.3	6.0	5.0	4.0	3.3	5.1
1 dose (%)**	0.0	0.0	0.0	4.2	5.9	6.8	8.1	9.9	14	14	16	16	22	22	23	21
2 doses (%)**	0.0	0.0	0.0	3.9	9.7	12	13	13	14	15	19	25	31	49	55	57

Supplementary Table 1. Parameter values used in the model. *Susceptibility for age group i is stated relative to susceptibility for age 60-64 years. **Representing the Auckland metro region population as at 3 August 2021, the doses which are assumed effective on 17 August 2021.

Acknowledgements

The authors acknowledge the support of the New Zealand Ministry of Health, StatsNZ, and the Institute of Environment Science and Research in supplying data in support of this work. The authors are grateful to Matt Parry and the COVID-19 Modelling Steering Group for feedback on this work. This work was funded by the New Zealand Ministry of Business, Innovation and Employment COVID-19 Programme and Te Pūnaha Matatini, Centre of Research Excellence in Complex Systems.

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1. Steyn, N., et al., *A COVID-19 Vaccination Model for Aotearoa New Zealand.* pre-print https://www.tepunahamatatini.ac.nz/2021/06/30/a-covid-19-vaccination-model-for-aotearoa-new-zealand/, 2021.
2. Hewitt, J. et al Sensitivity of wastewater-based epidemiology for detection of SARS-CoV-2 RNA in a low prevalence setting.