COVID-19 Modelling Aotearoa

Modelling Covid-19 dynamics in New Zealand August 2022 to February 2023

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Since July 2022, Covid-19 Modelling Aotearoa have been using a compartment-based ordinary differential equation (ODE) model to simulate the spread of Covid-19 in Aotearoa New Zealand. This age-structured model includes waning of vaccine-derived and infection-derived immunity, immune evasion of new Omicron subvariants, age-dependent hospitalisation and death rates, and changes in transmission resulting from behavioural and policy changes. The model is calibrated to data on Covid-19 cases, hospitalisations and deaths using an approximate Bayesian computation (ABC) method. A detailed description of the underlying model and fitting procedure as applied to the BA.5 wave in July 2022 can be found in Lustig et al. (2023).

The model has been periodically updated to reflect the changing transmission and immunity landscape in New Zealand. This document is a technical report summarising the different modelling assumptions and results relating to changes in transmission and immunity between August 2022 and February 2023. It includes:

- A description of the fitting method used to calibrate the model to epidemiological data.
- A description of how the model was used to estimate the potential impact of behavioural and policy changes at key time points.
- A description of the observed Omicron subvariants in New Zealand and how these were implemented in the model.

- A comparison of the model's outputs and data produced after each change in modelling assumptions.
- A note on possible factors leading to the reduction in observed Covid-19 case fatality ratio since September 2022.

Model fitting and parameter estimation

The model is based on numerous parameter assumptions: some of these values are fixed, others are fitted using an approximate Bayesian computation (ABC) rejection method. In this method, random combinations of parameter values drawn from their 'prior' distributions are trialled. The 1% of combinations that produce the best fit to the data are retained, forming an approximate posterior distribution. The results presented here are the best-fitting 150 parameter combinations from 15,000 independent draws from the prior. Graphs show the best-fitting model trajectory (i.e. the single trajectory with the smallest value of the distance function) and a 95% curvewise confidence interval, which is an envelope containing 95% of all retained trajectories.

Currently, we fit our model to the following data supplied by the Ministry of Health: new daily infections in a routinely tested cohort of border workers (up to July 2022), total and age-stratified daily reported cases of Covid-19, total and age-stratified daily hospital admissions, and total daily deaths. The age-stratified daily cases and hospital admissions are included for each age group as a proportion of the total output. The distance function measures the difference between model output and each of these time series, with equal weights. The definition of the distance function has been modified since our last published work (Lustig et al., 2023) (see Figure captions for details).

It is worth noting that multiple different combinations of parameter choices can result in simulations that give an equally good fit to empirical data. It is therefore important to consider modelling results as an ensemble of plausible trajectories that are consistent with historical data, subject to the constraints and assumptions of the model.

Below we report all assumptions for the fitted parameters, as well as the accepted range of parameter values, and the parameter set that gave the current best fit. For the full set of assumptions around the fixed parameters, refer to the Supplementary Material of Lustig et al. (2023).

March 2022 behavioural changes assumptions

The model includes several fitted parameters to reflect the behavioural relaxation that occurred starting after the first Omicron peak in March 2022. These changes were modelled through an increase in transmission and a relaxation of the contact matrix to rates more similar to those observed pre-pandemic. The magnitude and timing of these changes were estimated by fitting model outputs to data (see Table 1).

September 2022 and future policy change assumptions

Assumptions before decision to end Covid-19 Protection Framework in September 2022
In August 2022, we investigated the potential transmission increases that might occur as a result of changing isolation behaviours of confirmed cases and mask use after the Covid-19 Protection Framework (CPF) change planned for mid-September 2022. The estimates of transmission increases are subject to significant uncertainty. For example, the effect of ending legal requirements for specific actions (e.g. mask wearing, case isolation, contact quarantine) depends not only on the effect of those actions on individual-level transmission risk, but also on the number of people complying with those actions before the policy change, and the number voluntarily continuing with the actions after the change.

Before the CPF change, we provided a number of different possible scenarios of transmission increase. Here we show two indicative scenarios modelling: (1) the end of mask mandates and the requirement for household contacts to quarantine, but with high rates of testing and prompt isolation of positive cases (Figure 1); and (2) additionally changing from requirements to guidance for case isolation (Figure 2). The Covid-19 Modelling Aotearoa Network Contagion Model (Covid Modelling Aotearoa, 2022) estimated the approximate magnitude of transmission increases in these two scenarios as 8.5% and 20.5% respectively, with a range of uncertainty (see Figure 7). Table 2 also shows the relative change in cumulative cases, hospital admissions and deaths in the short and long term, for these two scenarios, plus an additional sensitivity analysis on the second scenario of a 17% (optimistic) and 24% (pessimistic) increase in transmission.

Assumptions after October 2022
After October 2022, the parameters relating to the transmission change following the September 2022 mask use and quarantine policy change (size of increase in transmission, starting date for the increase, number of days over which the increase occurs - see Table 1) were fitted by the model, using empirical data for the two months following the policy change (Figure 3). The best-fit value for the increase in transmission

was found to be 22% with an interquartile range of 16-24%. Figure 7, produced using CMA's network model, can be used to interpret this percentage increase in terms of isolation behaviour.

November 2022 variant of concern assumptions

Assumptions in November 2022

We assumed that, on 22 November 2022, a new immune evasive subvariant or combination of subvariants became dominant. This is a highly simplified model of the effect of a number of Omicron subvariants exhibiting growth advantages at this time including BA.2.75, BQ.1.1 and CH.1.1 lineages (ESR, 2022). We do not attempt to model these subvariants individually, but instead assume that their net effect can be captured via a reduction in the level of population immunity. At the time, international estimates (UK Health Security Agency, 2022) of the growth advantage of subvariants, such as BQ.1.1, relative to the resident BA.5 subvariant were comparable to the previously observed growth advantage of BA.5 relative to BA.2. This immunity change is modelled as having an equivalent effect to a sudden waning in immunity as the new variant(s) become dominant.

We assumed that this change in immunity was correlated to the one experienced with the BA.5 variant in June 2022, as described in Table 1. That is, trajectories in the ensemble that have parameter values corresponding to a higher level of immune evasion due to the variant in July 2022 will also have a higher level of immune evasion associated with the new variants in November. This assumption is made solely for the purposes of convenience in implementing the November variant model. Model results are shown in Figure 4. Assumptions regarding the level of immune evasion were later revisited (see next paragraph) once they could be informed by empirical data.

Assumptions after January 2023

In January 2023, we revisited our assumptions regarding the November 2022 variant of concern model using the December 2022 data. The best fitting scenario (Figure 5) was obtained by using an immune evasion parameter of *vocEvade2* = 0.25, applied on 15 November 2022, which produced a much smaller wave than the original November assumptions (see above). This value of the immune evasion parameter *vocEvade2* is approximately half the midpoint of the range of values used in the results provided in December 2022 (Figure 4), indicating that the net immune evasive effect of the

November 2022 lineages was significantly smaller than that of the BA.5 subvariant in July 2022.

Assumptions on time-varying reporting rates

Since our latest published work on the model (Lustig et al, 2023), we have transitioned from an assumed static reporting rate for clinical cases (drawn from a uniform prior U[0.35-0.75]) to a time-varying, age-dependent reporting rate in three broad age classes. For each of these three age groups, we assume a constant reporting rate until 30 April 2022, and then a linearly declining reporting rate from 1 May 2022. For our latest simulations, produced in early March 2023, we used fixed values for case reporting probabilities before 30 April 2022 and after 1 January 2023, with a linear decrease between those two dates, and an overall scaling multiplier applied to all reporting rates with a fitted value drawn from a uniform distribution U[0.8, 1.2] (see Table 1). The fifth row of graphs in Figure 6 illustrates this trend.

Note on the September 2022 drop in fatality rate

Since September 2022, the observed Covid-19 case fatality ratio (based on deaths for which Covid-19 was the underlying cause or a contributory factor) has decreased and the model results tend to overestimate daily deaths (Figure 4). This could be due to several factors:

- The distribution of new infections within the model's oldest age group (over 75 years old, which accounts for a disproportionately large fraction of Covid-19 deaths) could have shifted towards the younger end of the group, meaning relatively fewer infections in the older, more vulnerable members of this age bracket. Figure 8a-b shows that new cases over 85 years old dropped from about 20% to about 15% of this age group, and there was a drop in the average age of new cases in this group from about 78.5 to 77.5 years old. This could also reflect a reduction in the number of new infections in particularly high-risk settings, e.g. aged-residential care.

- In addition to a shift in the age distribution of new infections, there has also been a drop in the age-specific case fatality ratio in older age groups (Figure 8c),

especially those over 90 years old where the rate dropped from around 10% to around 5% between August and October 2022. One possible explanation for this observation is that the increased protection against death following a 4th dose of the vaccine (which was primarily given to older individuals in July-August 2022) could be higher than assumed by the model. Alternatively, the model could be underestimating the protection against death as a result of prior infection.

- The model does not take into account the increased use of antivirals since the broadening of the eligibility criteria on 14 September 2022, which might have resulted in a decrease in hospitalisation and/or fatality rates in older age groups.

Table 1. Assumptions on parameter values used in the ODE model. Description of all parameters fitted using the ABC method, together with the prior uniform range of values sampled, interquartile range of the accepted posterior distribution, and 'best fit' parameter set for parameters relating to transmission changes, case reporting, hospitalisation rate, fatality rate, and waning immunity. This table was updated with the posterior ranges and best fit values resulting from fitting the model to data until 25 February 2023.

Fitted parameter	**Description**	**Tested range (prior)**	**Accepted range (IQR of posterior)**	**Value for the best fit trajectory**
seedDate	Omicron seeding date	16-22 Jan '22	17-20 Jan '22	19 Jan '22
Transmission changes due to behaviour and policy changes				
relaxAlpha	Relaxation towards normal levels of mixing between ages (0 = no relaxation; 1 = pre-pandemic mixing)	0-0.8	0.32-0.64	0.2
MRampDays	Time period over which the relaxation occurs	50-90 days	61-80 days	61 days
Ct	Transmission multiplier used until the first transmission ramp-up	0.58-0.78	0.67-0.71	0.65
CtRampStart1	Starting date of first transmission ramp-up and behavioural relaxation	5-15 Mar '22	8-13 Mar '22	11 Mar '22
CtRampDays1	Number of days over	35-75 days	50-66 days	75 days

	which the first transmission ramp-up occurs			
CtRamp1	New transmission multiplier at the end of first ramp-up	0.89-1.31	1.06-1.24	1.25
CtRampStart2	Starting date of second transmission ramp-up	10-20 Sep '22	13-18 Sep '22	11 Sep '22
CtRampDays2	Number of days over which the second transmission ramp-up occurs	1-19 days	7-15 days	11 days
CtRamp2	Total transmission increase of second transmission ramp-up, as a % of the new transmission multiplier defined by *CtRamp1*	+10-30%	+15-24%	+16%
Reporting rate parameters (values used from March 2023)				
pTest1_030	Case reporting probability for clinical infections until 30 Apr 22 for 0-30 yrs	-	-	50%
pTest2_030	Case reporting probability for clinical infections from 1 Jan 23 for 0-30 yrs	-	-	10%
pTest1_3060	Case reporting probability for clinical infections until 30 Apr 22 for 30-60 yrs	-	-	60%
pTest2_3060	Case reporting probability for clinical infections from 1 Jan 23 for 30-60 yrs	-	-	40%
pTest1_60p	Constant case reporting probability for clinical infections for 60+ yrs	-	-	75%
pTestMult	Overall scaling factor on case reporting probabilities	0.8-1.2	1.01-1.14	1.18
Hospitalisation and fatality rates				

IFRmult	Multiplier to assumed age-specific infection fatality ratio values	0.4-1.2	0.49-0.65	0.46
IHRmult	Multiplier to assumed age-specific infection hospitalisation ratio values	0.25-0.75	0.56-0.68	0.64
Variants of concern				
vocEvade1	Relative immune evasion of the BA5 variant	0.1-0.7	0.26-0.53	0.43
vocEvade2	Relative immune evasion of the November 2022 variants	-	-	0.25
Waning of immunity (not variant related)				
waneRate	Waning immunity index defining the rate per day at which people move down the immunity ladder over time	0.0022-0.0067 day^{-1}	0.0052-0.0062 day^{-1}	0.0063 day^{-1}

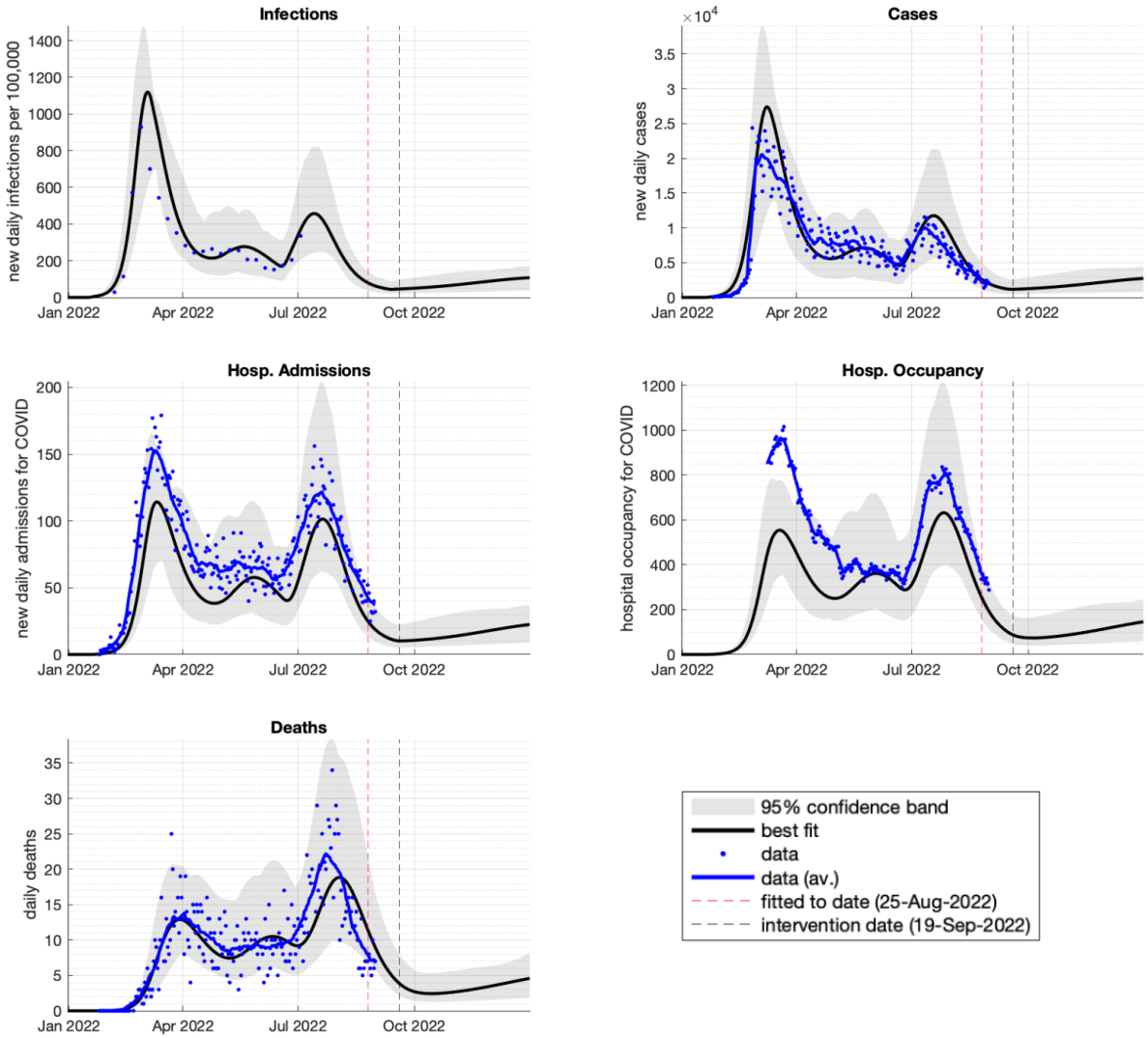

Figure 1. Results fitted to data up to 25 August 2022 modelling an assumed transmission increase (CtRamp2) of 8.5% resulting from the change in mask use and isolation policy on 19 September 2022. Graphs show the best fit trajectory (solid black line) and 95% confidence interval envelope (grey shaded area). Model was fitted to data (blue) on daily infections, total and age-stratified daily reported cases, hospital admissions, and daily deaths. Model assumed a constant reporting rate for clinical infections in all age groups, with value drawn from a uniform distribution U[0.35-0.75] and fitted to data as described in the text. Vaccination rates were based on the number of vaccine doses per day given to people in each age group according to data up to 4 July 2022, with future vaccine uptake according to MOH projections (see Lustig et al., 2023).

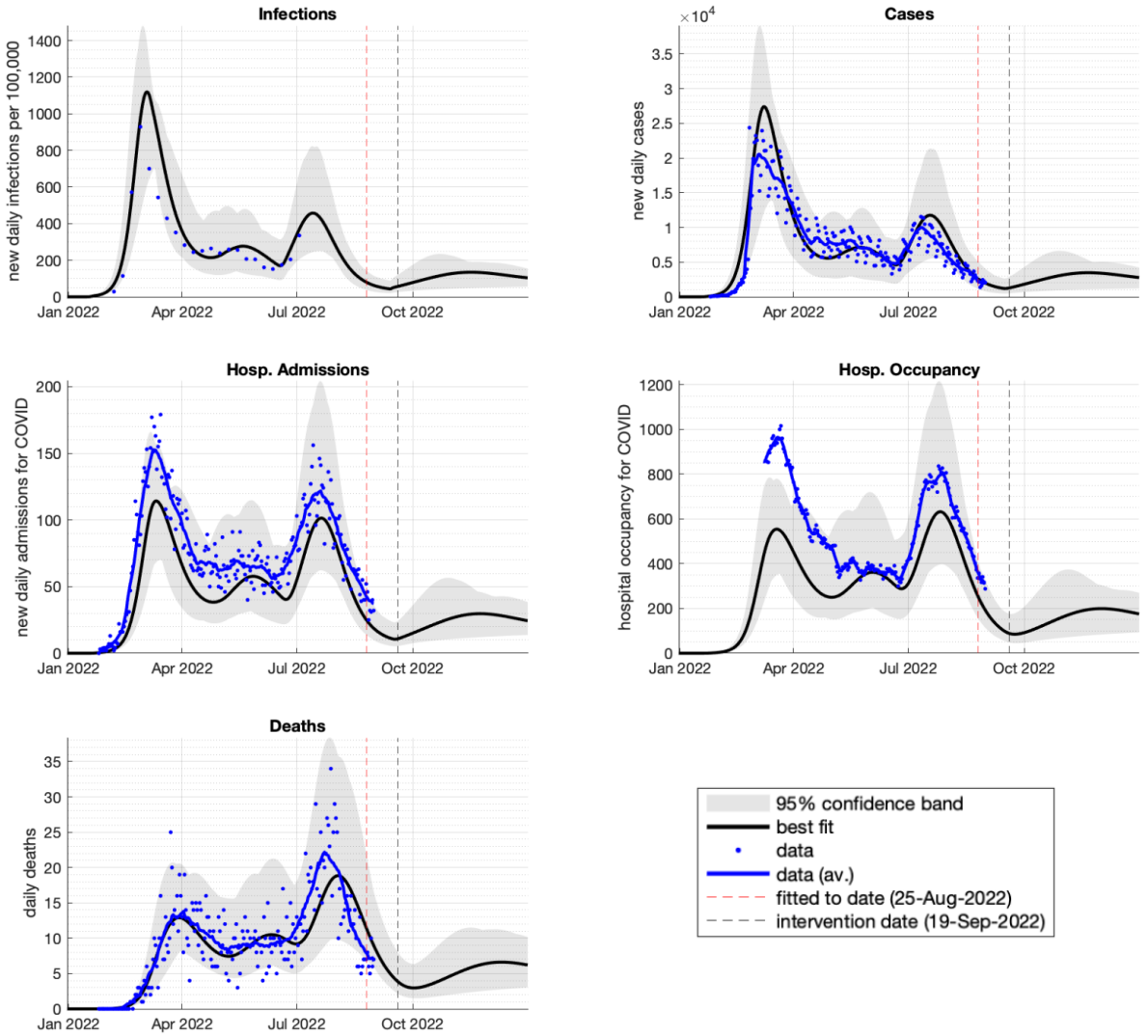

Figure 2. Results fitted to data up to 25 August 2022 modelling an assumed transmission increase (CtRamp2) of 20.5% resulting from the change in mask use and isolation policy on 19 September 2022. Graphs show the best fit trajectory (solid black line) and 95% confidence interval envelope (grey shaded area). Model was fitted to data (blue) on new daily infections in a routinely tested cohort, total and age-stratified daily reported cases, hospital admissions, and daily deaths. Model assumed a constant reporting rate for clinical infections in all age groups, with value drawn from a uniform distribution U[0.35-0.75] and fitted to data as described in the text. Vaccination rates were based on the number of vaccine doses per day given to people in

each age group according to data up to 4 July 2022, with future vaccine uptake according to MOH projections (see Lustig et al., 2023).

Table 2. Projected change in cases, hospitalisations and deaths under four scenarios for the magnitude of transmission increase on 19 September 2022, relative to the baseline model with no transmission change. Modelled short and long term impact on the mean cumulative number of cases, hospital admissions and deaths, and peak hospital occupancy, following a transmission increase of +8.5%, +17%, +20.5%, +24%, together with the percentage increase for each scenario compared to the baseline model.

	Short-term impact (cumulative from 15 days after implementation to 45 days after implementation)			**Long-term impact (cumulative for a year after implementation)**			**Peak hospital occupancy**
	Cumulative cases	*Cumulative hospital admissions*	*Cumulative deaths*	*Cumulative cases*	*Cumulative hospital admissions*	*Cumulative deaths*	
Baseline (0%)	30,000	250	60	810,000	6,630	1,460	160
Scenario 1 (+8.5%)	43,000 (+45%)	360 (+44%)	70 (+22%)	887,000 (+10%)	7,410 (+12%)	1,670 (14%)	160 (+1%)
Optimistic scenario (+17%)	63,000 (+113%)	520 (+111%)	90 (+55%)	956,000 (+18%)	8,120 (+23%)	1,870 (+28%)	190 (+17%)
Middle scenario (+20.5%)	74,000 (+150%)	610 (+148%)	100 (+72%)	982,000 (+21%)	8,400 (+27%)	1,950 (+34%)	210 (+32%)
Pessimistic scenario (+24%)	87,000 (+192%)	710 (+190%)	110 (+93%)	1,007,000 (+24%)	8,670 (+31%)	2,030 (+39%)	250 (+51%)

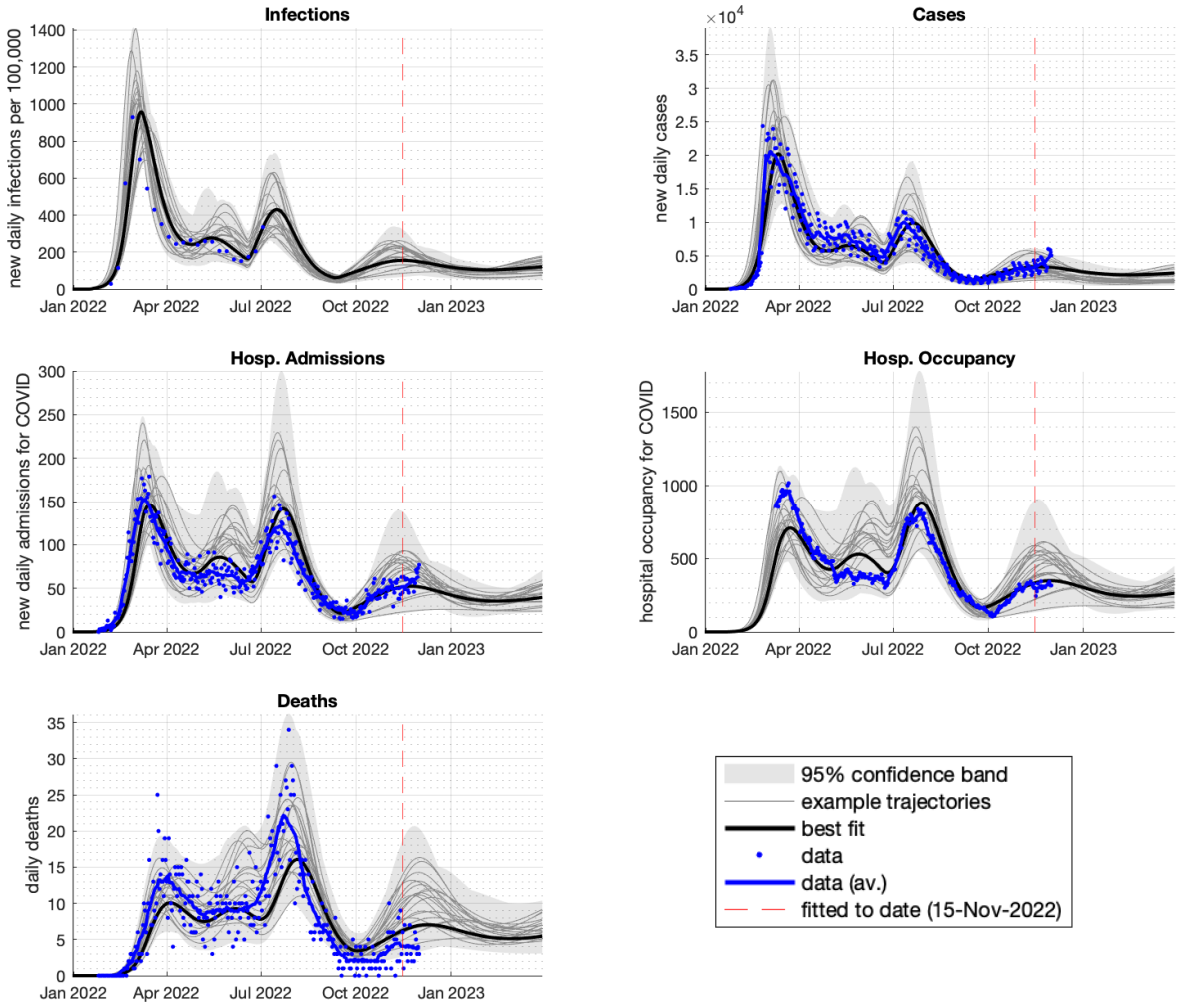

Figure 3. Results fitted to data up to 15 November 2022 assuming no future variant. Graphs show the best fit trajectory (solid black line), 95% confidence interval envelope (grey shaded area), and a random sample of 10 of the 150 accepted model trajectories (grey solid lines). Model was fitted to data (blue) on new daily infections in a routinely tested cohort, total and age-stratified daily reported cases, hospital occupancy, and daily deaths. Model assumed an age-dependent reporting rate for three different age groups (0-25, 25-65, 65+ yrs), with a constant value until 30 April 2022 and a negative slope to model a linear decrease in reporting rate from 1 May 2022, with a lower bound of 1%. Reporting rate parameters and slopes were fitted to data using the ABC method described in the main text. Vaccination rates were based on the number of vaccine doses per day given to people in each age group according to data up to 10 October 2022, with future vaccine uptake according to MOH projections (see Lustig et al., 2023) scaled to match cumulative doses as at 10 October 2022.

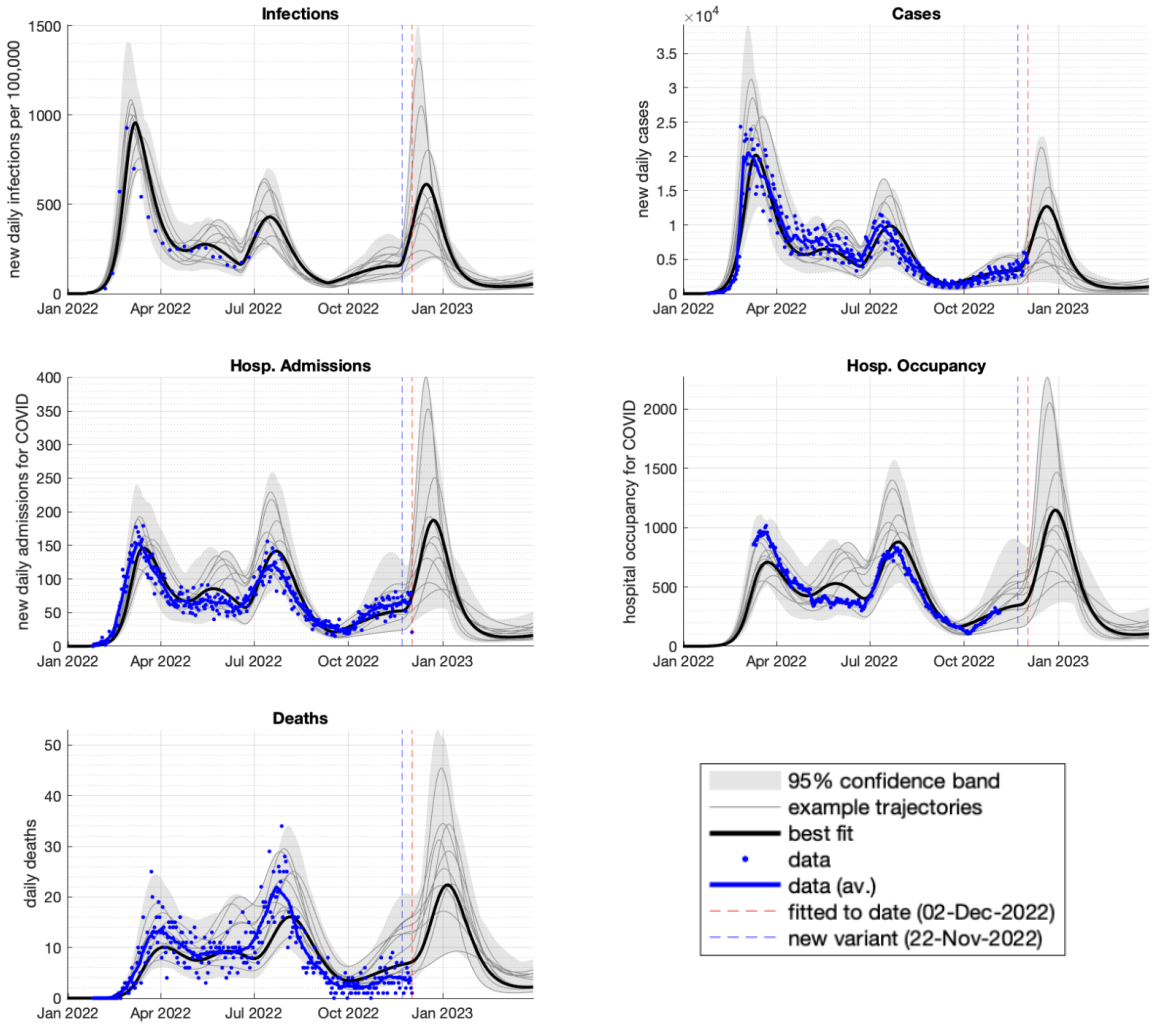

Figure 4. Results fitted to data up to 2 December 2022 modelling the potential impact of the immune evasive Omicron lineages that were increasing in frequency in October-November 2022. Assumed range of values for vocEvade2 [0.31, 0.54]. Graphs show the best fit trajectory (solid black line), 95% confidence interval envelope (grey shaded area), and a random sample of 10 of the 150 accepted model trajectories (grey solid lines). Model was fitted to data (blue) on new daily infections in a routinely tested cohort, total and age-stratified daily reported cases, hospital occupancy, and daily deaths. Model assumed an age-dependent reporting rate for three different age groups (0-25, 25-65, 65+ yrs), with a constant value until 30 April 2022 and a negative slope to model a linear decrease in reporting rate from 1 May 2022, with a lower bound

of 1%. Reporting rate parameters and slopes were fitted to data using the ABC method described in the main text. Vaccination rates were based on the number of vaccine doses per day given to people in each age group according to data up to 10 October 2022, with future vaccine uptake according to MOH projections (see Lustig et al., 2023) scaled to match cumulative doses as at 10 October 2022.

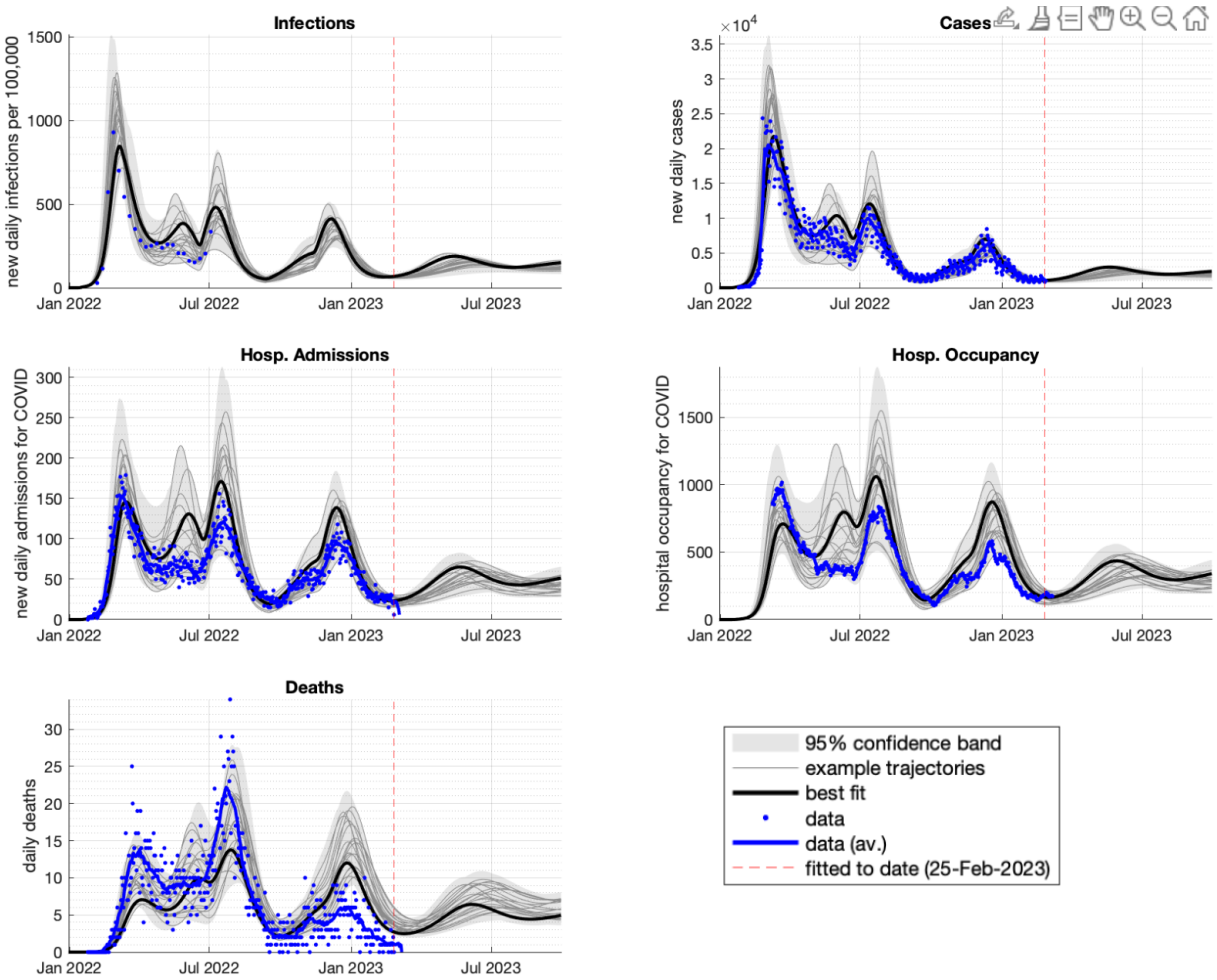

Figure 5. Results fitted to data up to 25 February 2023 modelling the impact of the immune evasive Omicron lineages that were increasing in frequency in October-November 2022. Estimated value for *vocEvade2* = 0.25 based on December data. Graphs show the best fit trajectory (solid black line), 95% confidence interval envelope (grey shaded area), and a random sample of 20 of the 150 accepted model trajectories (grey solid lines). Model was fitted to data (blue) on new daily infections in a routinely tested cohort, total and age-stratified daily reported cases, total and age-stratified daily hospital admissions, and daily deaths. Model assumed an age-dependent reporting rate for three different age groups (0-30, 30-60, 60+ yrs), with a constant value until 30 April 2022, a linearly declining rate until 1 January 2023, followed by a

constant value from that date onwards. The values of these reporting rate parameters were estimated based on temporal trends in observed age-specific case-hospitalisation ratios (see 4th row of Figure 6), adjusted by a fitted multiplier drawn from a uniform distribution U[0.8-1.2] (Table 1). Vaccination rates were based on the number of vaccine doses per day given to people in each age group according to data up to 13 February 2023, with no subsequent vaccination uptake assumed after this date.

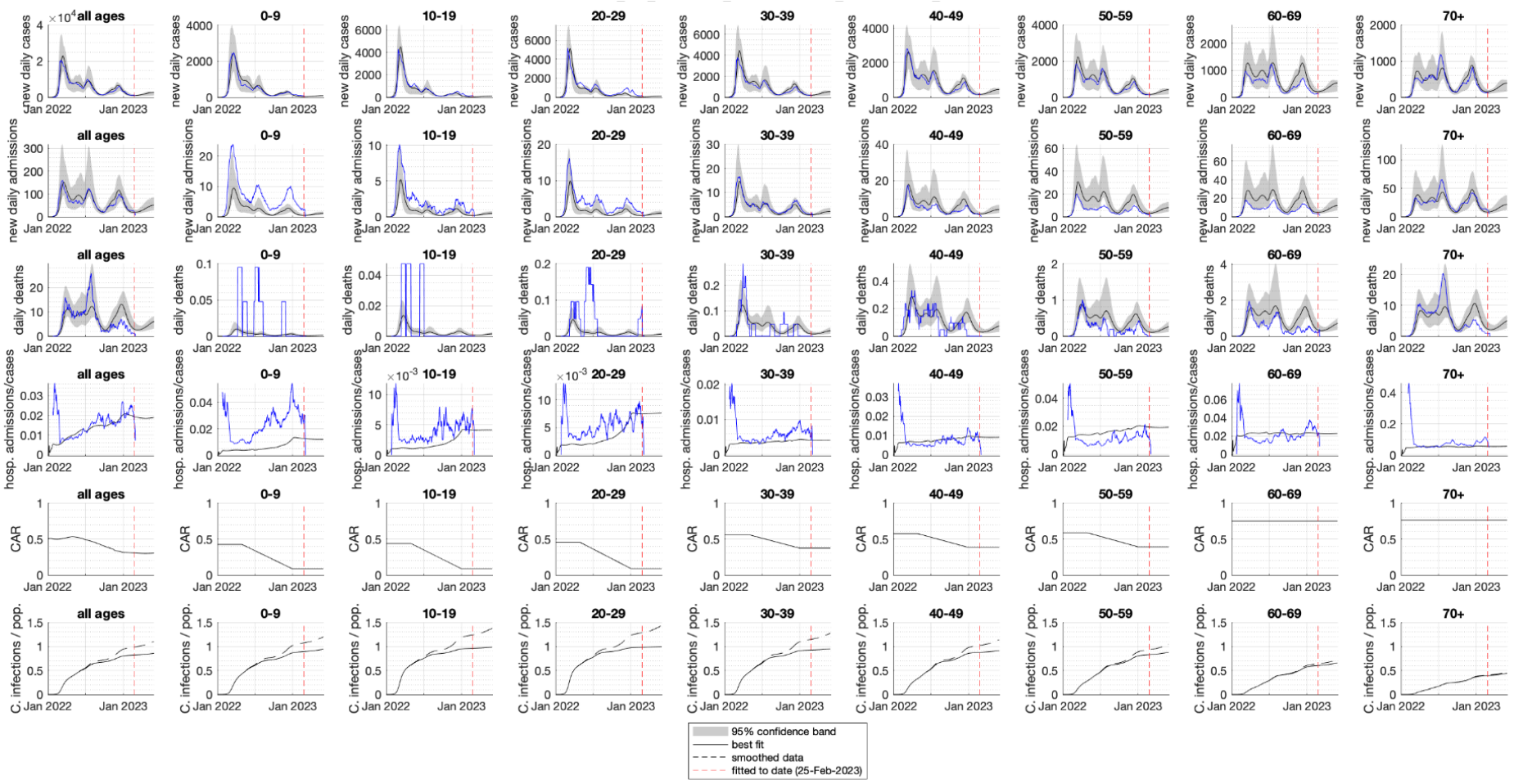

Figure 6. Results fitted to data up to 25 February 2023, split into 10-year age groups. Graphs show the best fit trajectory (solid black line), and 95% confidence interval envelope (grey shaded area) for daily cases, hospital admissions, deaths, hospitalisation/case ratio, case ascertainment rate, and cumulative infections/total population (solid curves = first infections only, dashed curves = all infections). Model was fitted to data (blue) as described in Figure 5.

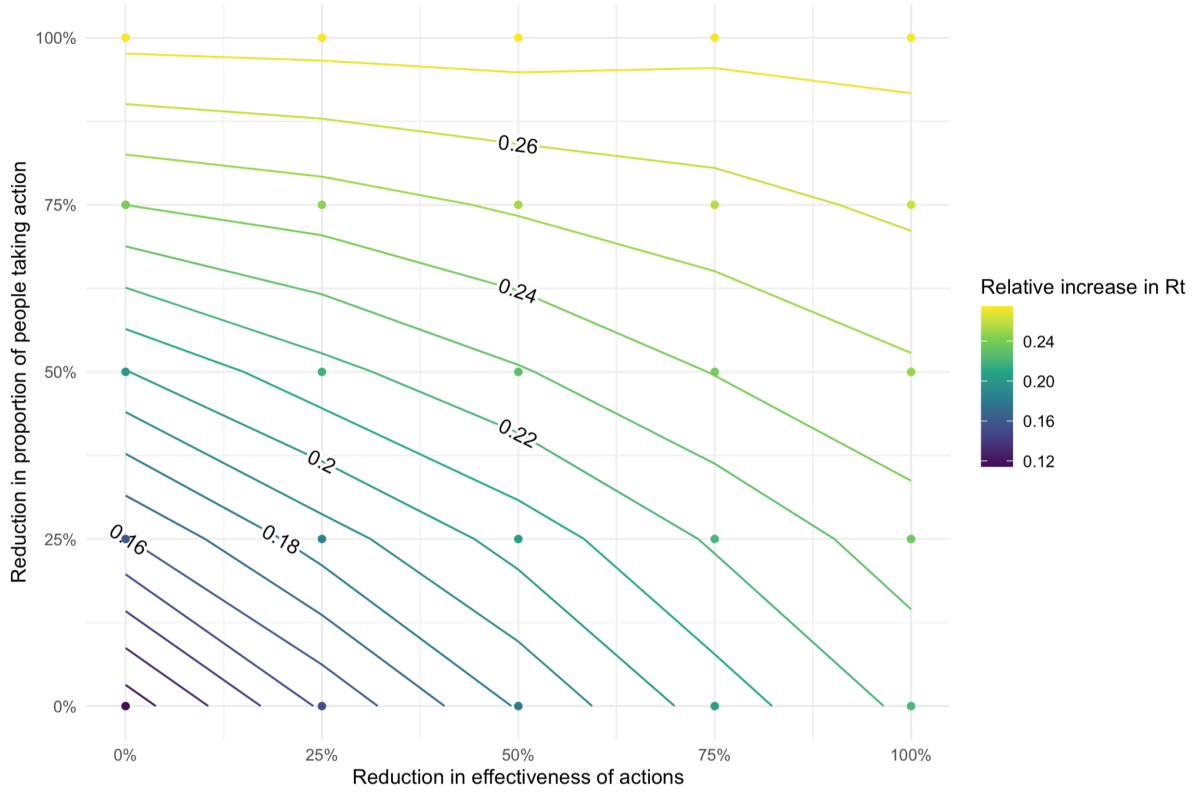

Figure 7. Contour plot showing the relative instantaneous increase in transmission (Rt) due to a change in case isolation behaviour compared to an August 2022 baseline. The value at the origin of this plot is 11.4%, which is the estimate of increase in transmission due to ending mask mandates and changing household contact quarantine requirements to 'guidance to test if symptomatic. Results are from the network contagion model (Covid-19 Modelling Aotearoa, 2022).

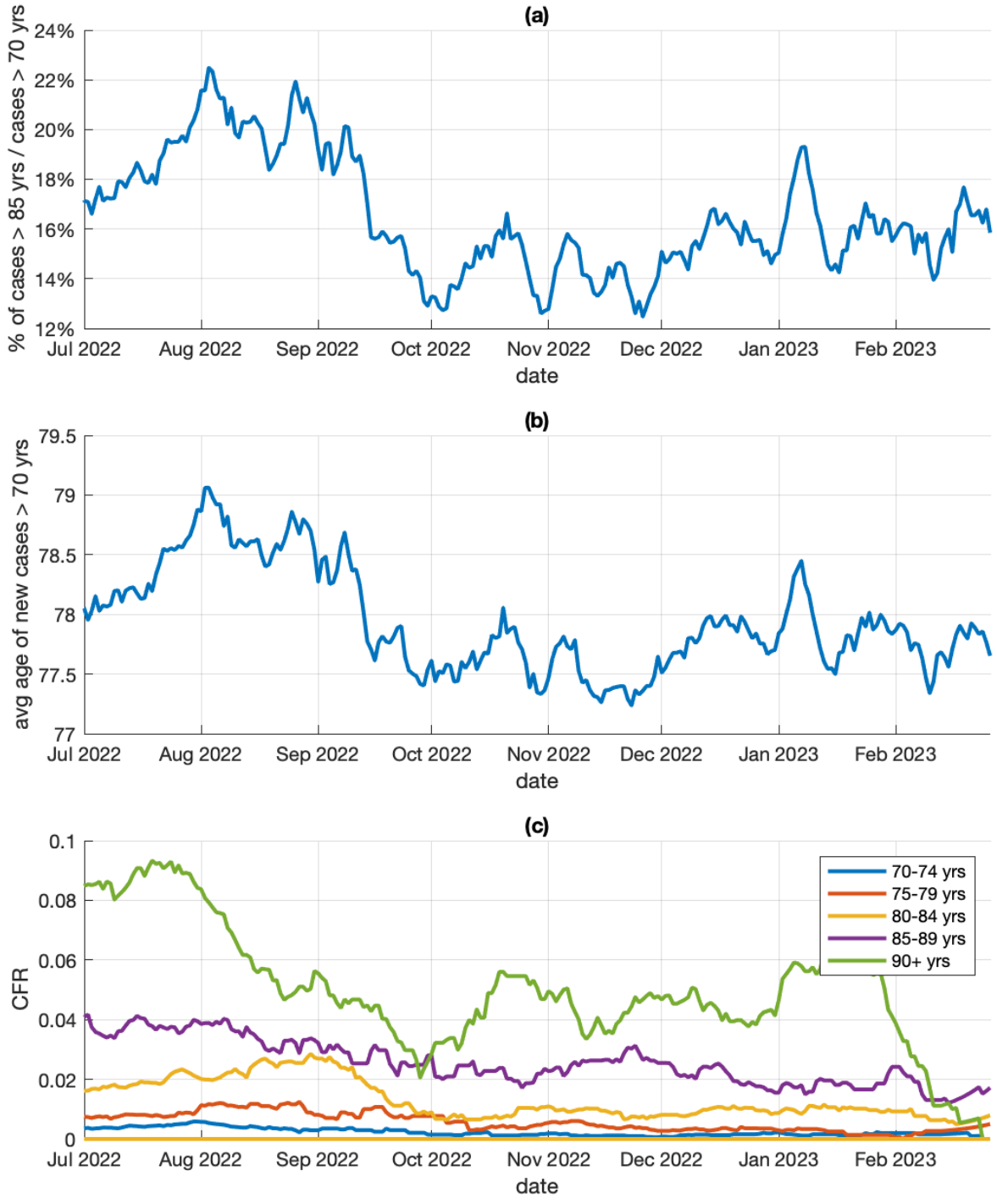

Figure 8. Drop in average age of cases and drop in age-stratified case fatality ratio for those aged over 70 years. (a) Rolling 7-day average of the proportion of cases over 70 years old that

are also over 85 years old. (b) Rolling 7-day average of the mean age of new daily cases over 70 years old. (c) Case fatality ratio for cases in the 70-74, 75-79, 80-84, 85-89, 90+ years age groups.

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References

1. Covid Modelling Aotearoa (2022). Note on CMA's modelled scenarios of changing isolating behaviour and transmission.
2. ESR (2022) Genomics Insights Dashboard. https://esr2.cwp.govt.nz/our-expertise/covid-19-response/covid19-insights/genomics-insights-dashboard
3. Lustig, A., Vattiato, G., Maclaren, O., Watson, L. M., Datta, S., & Plank, M. J. (2023). Modelling the impact of the Omicron BA. 5 subvariant in New Zealand. *Journal of the Royal Society Interface*, *20*(199), 20220698.
4. UK Health Security Agency (2022). SARS-CoV-2 variants of concern and variants under investigation in England. Technical briefing 47. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1115077/Technical-Briefing-47.pdf