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Modelling to support a future COVID-19 strategy for Aotearoa New Zealand

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Executive Summary

- Aotearoa New Zealand is on track to vaccinate upwards of 80% of those aged over 12 against COVID-19 with the Pfizer/BioNTech mRNA vaccine. Recent announcements by Pfizer and BioNTech suggest that the vaccine may soon be approved for use in children aged 5-11 years. This means it is possible that Aotearoa could achieve vaccine coverage across the total population of more than 90%.
- We consider how these high rates of coverage might reduce the health burden from COVID-19 if combined with moderate public health measures to reduce transmission of the virus. Scenarios are evaluated using the Te Pūnaha Matatini vaccine model, using current data about vaccine effectiveness with respect to the Delta variant. As the effects of the vaccine on transmission remain uncertain, we consider three levels of vaccine effectiveness: high, central, and low to illustrate a range of possibilities.
- Attaining population immunity would significantly reduce health impacts, but this a function of the particular characteristics of the virus, the structure of the population, the distribution of immunity in that population, and other measures that can be put in place, all of which can change over time. Nonetheless, it is not thought to be possible to achieve widespread population immunity to the Delta variant by vaccination alone, which means that moderate public health measures will be needed to augment the vaccine programme.
- Here we assume a suite of moderate and sustainable public health measures are maintained, such as some combination of mask use, ventilation, some density/capacity restrictions for indoor venues, support for people to isolate, and/or vaccine certificates. We also assume that a test-trace-isolate-quarantine system is operating either at levels that are high (most likely at low case-loads) or reduced (most likely at high case-loads). We do not consider the use of stay-at-home orders here (i.e. Alert Level 3 or 4).
- We find that there are scenarios where, through a combination of high vaccine coverage (including amongst those aged 5-11) and moderate public health measures, population immunity is achieved, resulting in very low mortality burden. For example, with 90 per cent vaccine coverage of the population over the age of 5, a suite of moderate public health measures and an effective test, trace and isolate system, the modelling suggests there would be around 500 hospitalisations and 50 fatalities from COVID-19 over a one year period.
- There are scenarios where, despite a high vaccination coverage, population immunity is not achieved, resulting in a disease mortality burden that is an order of magnitude greater. For example, with 80 per cent vaccine coverage of the population over the age of five and moderate public health measures, the modelling suggests there would be around 60,000 hospitalisations and 7,000 fatalities per year from COVID-19. Such outcomes could be mitigated if more restrictive control measures, akin to current Alert Levels 3 or 4, were utilised.

- Nonetheless, the results suggest that a combination of high levels of vaccination within the community, a strong test-trace-isolate-quarantine system (assuming case numbers are kept sufficiently low) and moderate public health measures may be enough to attain population immunity, greatly reducing the need for strong public health measures, such as stay-at-home orders and workplace closures.

Introduction

As of 21 September 2021, 79% of Aotearoa New Zealand's eligible population have either had at least one dose of the Pfizer-BioNTech vaccine against COVID-19 or are booked to have a dose [1]. Currently this vaccine is approved in Aotearoa for people over 12 years of age. On 20 September 2021, Pfizer and BioNTech announced that trials for this vaccine for 5-11 year olds had proved successful, in that the vaccine had been found to be safe and effective, and that they intended to apply for approval around the world [2]. This raises the possibility that Aotearoa may be able to achieve very high levels of vaccine coverage, something that would greatly reduce the mortality burden from COVID-19 if combined with moderate public health interventions.

In order to keep annual mortality from COVID-19 at levels similar to or below those experienced from seasonal influenza, for instance, the effective reproduction number, R_{eff}, of the virus must be kept close to or below 1 by a combination of vaccination, targeted measures such as case isolation, and other control measures. Results from both Te Pūnaha Matatini's SEIR vaccination model [3] and the ESR model [4] suggest that if the reproduction number is even slightly greater than 1, fatalities would be measured in thousands, despite high vaccine coverage. As the Delta variant is thought to have a reproductive number of $R_0 \sim 5.5 - 6.5$, population immunity ($R_{\text{eff}} < 1$) is likely to be extremely difficult to achieve by vaccination alone. Thus it is probable that other control measures will be needed on top of vaccination to deal with COVID-19 outbreaks for the foreseeable future. In this short note we consider scenarios with different combinations of vaccine effectiveness, vaccine coverage, and additional public health and social measures.

The work here is based on Te Pūnaha Matatini's vaccination model [3]. This model is age-structured, but otherwise does not capture population heterogeneity in vaccination or contact rates. This means that while R_{eff} could be less than one, on average, across the population, there may still exist communities with $R_{\text{eff}} > 1$ in which a significant outbreak could occur. It is also likely that R_{eff} would vary seasonally and is likely to be higher during school and university terms and higher in winter than in summer months. Thus, estimates of fatalities made here may be optimistic. Furthermore, we have used baseline assumptions about the effectiveness of the vaccine [5,7] that do not consider immune escape or waning immunity.

Nonetheless the results here demonstrate the considerable benefits of achieving high vaccination coverage in the coming months. It suggests that a combination of high levels of vaccination within the community, a strong test-trace-isolate-quarantine (TTIQ) system and moderate public health measures may be enough to attain population immunity, which would greatly reduce the need for stay-at-home orders and tight border restrictions in 2022.

Key model assumptions and inputs

- We assume $R_0 = 6.0$ to model the Delta variant, which remains dominant globally and is the variant responsible for the Auckland 2021 outbreak.
- We assume that a baseline suite of moderate public health measures and mitigations are in place than provide a 17% reduction in transmission.
- A TTIQ system provides an additional reduction in transmission of either 10% (limited TTIQ – assuming that only limited contact tracing is possible) or 20% (full TTIQ – assuming effective contact tracing).

- Vaccine coverage is assumed to be uniform across eligible age groups and it is assumed that everyone who is vaccinated has had both doses of the Pfizer/BioNTech mRNA vaccine.
- Vaccine effectiveness assumptions, as shown in Table 1, are the same as used in [3] with the assumption of no waning immunity. Although the effectiveness of the vaccine against severe disease from the Delta variant is reasonably well established, the rates of breakthrough infections and any subsequent rates of transmission in vaccinated individuals are less well known.

Effectiveness	Central	Lower Effectiveness	Higher Effectiveness
Against infection	70%	50%	90%
Against transmission given infection	50%	40%	50%
Against severe disease given infection	80%	80%	80%
Overall transmission reduction	85%	70%	95%
Overall protection against severe disease	94%	90%	98%

Table 1. Vaccine effectiveness parameters chosen to reflect estimates of the effectiveness of the Pfizer-BioNTech mRNA vaccine after 2 doses [5].

- Simulated outbreaks are seeded with an average of 1 case per day arriving at the border and entering the community. This approximately represents a situation where current tight border restrictions are relaxed, but strong border controls remain in place to limit the number of infectious travel-related cases entering the community Results are relatively insensitive to this assumption when $R_{\text{eff}} > 1$, but will be sensitive to the border settings and corresponding in flow of infected travellers for scenarios where $R_{\text{eff}} < 1$.
- Age-stratified hospitalisation rates are as in [10] with a hazard ratio of 2.26 representing the increased severity of the Delta variant [6].
- The risk of fatality given hospitalisation is as in 103]; see also [6].
- Mean length of hospital stay = 8 days [11].

Key caveats

- Although this model is age-structured, it neglects other forms of heterogeneity in the population. In particular, it neglects homophily in vaccine coverage, whereby people who are unvaccinated also tend to have contacts who are unvaccinated. Thus a high average coverage that allowed for population immunity with other measures may still leave small groups of people or communities below the required threshold, making them vulnerable to outbreaks and health impacts.
- There is still a high degree of uncertainty about the effectiveness of vaccines against the Delta variant, particularly for breakthrough infection and subsequent propensity to transmit. Furthermore immunity may wane over time. Our central vaccine effectiveness against infection and severe illness is comparable to that reported by Public Health England on 17 September 2021 for the Delta variant [7].
- Model outputs are sensitive to the assumed value of $R_0 = 6$ and assumed reductions in transmission due to baseline public health measures (17%), partial TTIQ (10%) and full TTIQ (20%) [7]. These are based on a combination of empirical data and modelling assumptions and are subject to uncertainty. In addition, the effect of such control measures may be different in future as a result of changes in behaviour in an environment where the population is highly vaccinated.

- Model results are intended as a guide to the relative benefits of different levels of vaccine coverage in the population rather than exact predictions or a detailed roadmap.
- Model simulations are run for a one year period. Additional health impacts are possible subsequent to this one year period, although the scale of these will depend more heavily on unknown variables including the rates of waning immunity to infection and to severe disease.

Results for an epidemic with baseline public health measures and TTIQ

The results presented here are for a 12-month period following the start of an outbreak. We have not included the effects of individual public health measures in this study. Instead we assume that a moderate suite of measures are in place and that these can be sustained for a long period of time. Such measures may include a combination of interventions such as:

- Improved air filtration and ventilation requirements, or where these cannot be met, mandatory mask use or some density or capacity restrictions for indoor venues
- Vaccine passports
- Support for people to isolate
- Rapid-testing at workplaces and schools

Two scenarios for TTIQ performance are considered:

1. Baseline public health measures (17% reduction in transmission) and limited TTIQ (10% reduction in transmission), giving a combined 25% reduction in R_{eff}.
2. Baseline public health measures (17% reduction in transmission) and full TTIQ (20% reduction in transmission), giving a combined 33% reduction in R_{eff}.

The first of these could be interpreted as a scenario where measures to contain outbreaks are relaxed or fail and a mitigated epidemic wave spreads through the population. High case numbers would mean that TTIQ is less effective and may rely primarily on widespread testing and isolation of symptomatic individuals and confirmed cases. In the second case, we assume that a fully effective TTIQ system can be maintained when case numbers are sufficiently low. Here, effective performance is set to be similar to that observed early in the Auckland August 2021 outbreak, based on the time cases were isolated or quarantined relative to the time of symptom onset. Future work will explicitly model the performance of the TTIQ system under different caseloads, but it is important to note that in general it will be easier to keep R_{eff} supressed when overall case numbers are low.

We consider a range of scenarios that combine a mix of vaccine effectiveness assumptions, vaccine coverage levels, and the two TTIQ performance tiers described above. This model does not attempt to capture in detail the effect of border controls. In scenarios where $R_{\text{eff}} > 1$, border controls have less of an effect on outcomes (unless very stringent), but they become important for determining cases when $R_{\text{eff}} < 1$. The scenarios here best represent situations with moderate border controls in place. In scenarios where $R_{\text{eff}} < 1$, real outcomes will be highly variable depending on the nature of each chain of infection and will be sensitive the number of border-related cases, which are not modelled here. Nonetheless, provided outbreaks are only seeded into communities where $R_{\text{eff}} < 1$, the mortality burden is expected to be lower than or comparable to seasonal influenza. Note that these scenarios ignore the effects of waning immunity, which may well be significant over the timescales considered here, but which could be mitigated with vaccine boosters.

Effective reproductive number

pVaxElig	R_{eff} with no mitigation			R_{eff} with baseline PH measures and limited TTIQ			R_{eff} with baseline PH measures and full TTIQ		
Over 12s	High VE	Cent VE	Low VE	High VE	Cent VE	Low VE	High VE	Cent VE	Low VE
70%	1.78	2.22	2.95	1.34	1.66	2.22	1.19	1.48	1.97
75%	1.63	2.04	2.79	1.22	1.53	2.09	1.09	1.36	1.86
80%	1.52	1.88	2.62	1.14	1.41	1.97	1.01	1.26	1.75
85%	1.44	1.75	2.47	1.08	1.31	1.85	0.96	1.16	1.65
90%	1.38	1.63	2.32	1.03	1.22	1.74	0.92	1.09	1.55
95%	1.33	1.54	2.18	1.00	1.15	1.64	0.89	1.03	1.46
Over 5s									
70%	1.53	2.05	2.85	1.15	1.54	2.14	1.02	1.37	1.90
75%	1.33	1.85	2.67	1.00	1.39	2.00	0.89	1.23	1.78
80%	1.15	1.66	2.50	0.87	1.25	1.87	0.77	1.11	1.67
85%	1.02	1.49	2.33	0.76	1.12	1.75	0.68	0.99	1.55
90%	0.93	1.33	2.17	0.70	1.00	1.63	0.62	0.89	1.45
95%	0.87	1.19	2.02	0.66	0.89	1.51	0.58	0.79	1.34

Table 2. The effective reproductive number R_{eff} for differing levels of vaccine coverage across the eligible population (5+ or 12+), different assumptions about vaccine effectiveness (high, central, and low), and different level of public health mitigation (no mitigation, baseline PH measures with limited TTE, baseline PH measures with full TTIQ).

Baseline public health measures and limited TTIQ

pVaxElig	Infections			Hospitalisations			Deaths			Peak beds occupied		
Over 12s	High VE	Cent VE	Low VE	High VE	Cent VE	Low VE	High VE	Cent VE	Low VE	High VE	Cent VE	Low VE
70%	1440522	2082185	2823390	94769	120339	149276	11844	15542	20102	13092	21113	33069
75%	1145338	1835476	2653898	68092	95426	126310	8307	12088	16792	7486	14642	26183
80%	835601	1570757	2475533	43224	71628	104065	5148	8886	13645	3491	9272	19990
85%	460831	1284468	2286397	19133	49483	82723	2218	6008	10688	1172	5136	14514
90%	78630	972073	2084118	2270	29768	62529	260	3539	7953	195	2316	9846
95%	12809	569508	1865801	218	12275	43815	26	1425	5481	13	752	6053
Over 5s												
70%	1051653	1747955	2577609	79738	109892	143037	9447	13669	18824	9371	17889	30732
75%	705384	1459872	2381811	49923	83670	119659	5681	10117	15482	4022	11423	23832
80%	193310	1143129	2174033	12203	58410	97075	1299	6838	12327	799	6215	17656
85%	5546	779614	1951199	311	34324	75511	33	3868	9392	10	2487	12292
90%	1454	171773	1709070	67	6030	55277	7	637	6719	2	438	7818
95%	708	7486	1441633	23	199	36822	3	21	4362	1	6	4328

Table 3. Total infections, hospitalisations, deaths, and peak hospital occupancy over a one year period for differing levels of vaccine coverage across the eligible population (5+ or 12+), different assumptions about vaccine effectiveness (high, central, and low), and with baseline PH measures and limited TTIQ.

Baseline public health measures and full TTIQ

pVaxElig	Infections	Hospitalisations	Deaths	Peak beds occupied

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Over 12s	High VE	Cent VE	Low VE	High VE	Cent VE	Low VE	High VE	Cent VE	Low VE	High VE	Cent VE	Low VE
70%	1202590	1848646	2619610	78877	106172	137348	9523	13271	17947	8490	15549	26732
75%	881494	1579662	2435510	52272	81674	114983	6151	10001	14820	4128	10089	20680
80%	444142	1288249	2240443	22573	58464	93456	2560	7004	11870	1394	5770	15310
85%	42338	962392	2032049	1720	36868	72984	191	4314	9126	130	2695	10688
90%	6210	461893	1807389	189	13796	53855	21	1557	6623	7	878	6877
95%	2415	52423	1562854	46	1103	36466	5	123	4407	1	83	3925
Over 5s												
70%	826378	1518616	2372654	62392	94809	130543	7129	11399	16653	5419	12657	24533
75%	387597	1209014	2162504	27032	68865	107743	2930	8039	13501	1603	7323	18483
80%	14122	861391	1938250	899	43757	85857	94	4936	10549	44	3319	13179
85%	2176	308699	1696232	124	13249	65146	13	1411	7832	3	848	8697
90%	954	13398	1431361	45	476	45968	5	50	5395	1	20	5120
95%	532	2948	1135485	18	79	28812	2	8	3292	0	2	2503

Table 4. Total infections, hospitalisations, deaths, and peak hospital occupancy over a one year period for differing levels of vaccine coverage across the eligible population (5+ or 12+), different assumptions about vaccine effectiveness (high, central, and low), and with baseline PH measures and full TTIQ.

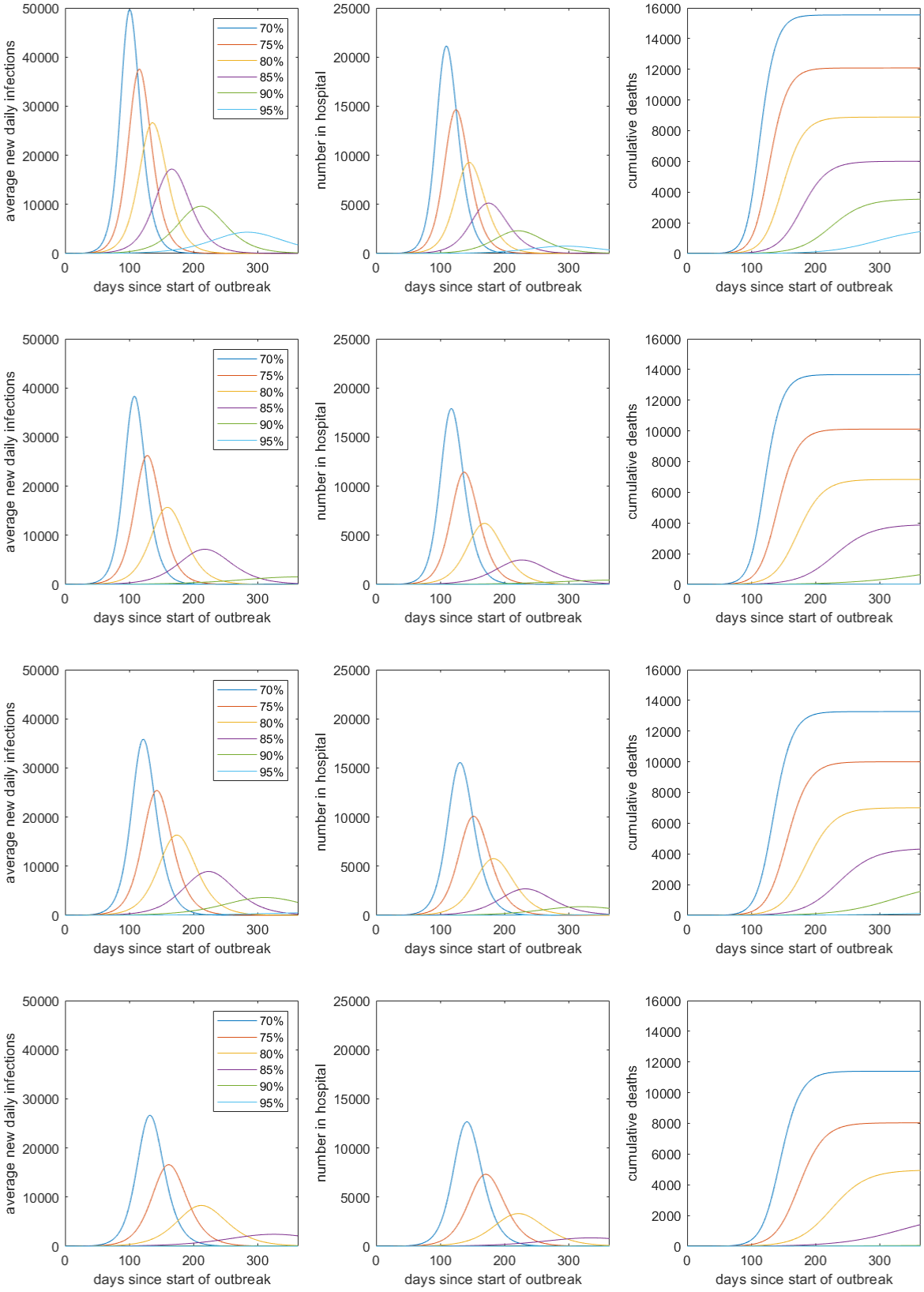

Figure 1. Average new daily SARS-CoV-2 infections, number of COVID-19 patients in hospital, and cumulative COVID-19 deaths over a 365 day period for different levels of vaccine coverage (from 70% to 95%) in: over 12s with limited TTIQ (first row), over 5s with limited TTIQ (second row), over 12s with full TTIQ (third row), over 5s with full TTIQ (fourth row). Results shown are for the central vaccine effectiveness assumptions.

Discussion

The results here illustrate the benefits of achieving levels of vaccination coverage higher than 90% of the eligible population. Even at 90% coverage of those aged over 12 and with moderate public health measures, there could still be high levels of population morbidity and mortality under conditions of low or waning vaccine effectiveness. These sorts of outcomes would generally be outside the capacity of the health system to cope, so they would likely require the imposition of more stringent measures including local school, business and university closures as well as targeted stay-at-home orders. There would also be significant infection rates in children. For example, with 90% of over 12s vaccinated with central vaccine effectiveness, baseline public health measures and fully effective TTIQ, the model estimates there would still be approximately 150,000 infections in children under 15. Although the risk of severe disease in these age groups is relatively low, the broader health impacts [9] and disruption to schools from such high infection rates would still be significant.

However if vaccination coverage is increased to 95% and/or into the 5-11 age group then the results suggest that moderate public health measures can result in $R_{\text{eff}} < 1$, leading to considerably better outcomes. A combination of high levels of vaccination within the community, a strong test-trace-isolate-quarantine system, and moderate public health measures would greatly reduce the need for stay-at-home orders and workplace closures.

The results suggest that it would be valuable to develop a suite of moderate public health interventions that can be sustained for a long period of time if required. Interventions such as mandated mask use, ventilation requirements and some density or capacity restrictions for indoor venues, rapid-testing at workplaces and schools, and support for symptomatic people, confirmed cases and close contacts to isolate should be investigated. Effort should also be given to strengthening the test-trace-isolate-quarantine system, which would be expected to operate for extended periods with low to moderate levels of cases in the community, possibly punctuated by larger outbreaks in parts of the community where vaccine coverage is lower due to reduced uptake or waning immunity. Such outbreaks may require significant surge capacity and may need to be accompanied by more stringent public health measures. However, the higher the vaccine coverage achieved, the less such measures will be needed.

The purpose of this report is to provide a broad guide to the relative benefits of different levels of vaccine coverage in terms of reducing potential health impacts of COVID-19 and therefore lessening the need for stringent restrictions to reduce transmission of SARS-CoV-2. Decisions about the nature and timing of changes in public health measures and border controls should be informed both by more detailed modelling based on up-to-date national and international data and by specific public health considerations. These include: current case numbers and transmission rates; vaccine coverage in specific communities and regions, including Māori and Pasifika vaccination rates; regional and national health system capacity and demands and contact tracing system capacity; seasonal factors including, for example, school/university terms and faster transmission in winter months; epidemiological characteristics of recent and current outbreaks.

Future modelling work will focus on specific public health interventions in more detail, including how these interventions interact with health system and contact tracing system capacity, border controls, and the frequency at which more stringent interventions may be needed. When $R_{\text{eff}} < 1$, the health outcomes are more moderate, but do become sensitive to the particular choice of border restrictions. Future work will investigate the relationship between outcomes and border restrictions.

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