Draft

Modelled Estimates for the Spread and Health Impact of Covid-19 in New Zealand: Revised Preliminary Report for the NZ Ministry of Health

27 February 2020

Dr Lucy Telfar Barnard, Prof Nick Wilson, Dr Amanda Kvalsvig, Prof Michael Baker (HEIRU, University of Otago Wellington; contact: michael.baker@otago.ac.nz)

Acknowledgements: We thank our Australian colleagues for their valuable work in providing modelling data on numbers of infected cases for different scenarios. Nevertheless, the additional analyses and interpretation in this document are those of the above named authors alone and do not necessarily represent the views of our Australian colleagues or the New Zealand Ministry of Health.

Key messages

- The future spread and health impact of this new disease are highly uncertain at present as there is limited evidence about the full spectrum of transmissibility, infection severity and impact of control measures. **This Report therefore can only represent potential future scenarios rather than predictions.**
- If substantially uncontrolled spread of disease occurs in NZ during 2020, our "plan for" scenario based on the modelling work by our Australian colleagues sees 65% of the population (3,230,000) contracting a Covid-19 infection, though only 34% of the population (1,680,000) would probably be symptomatic (typically mild disease). However, these could well be over-estimates if the disease is less transmissible in NZ than China (at least for January 2020 in China), if the summer and spring conditions in NZ slow the spread of disease (noting that other coronavirus infection is typically a winter phenomenon), and if control measures are more effective than we anticipate. Indeed, our "plan for" scenario is somewhat towards "worse case" and the most likely outcome for NZ is probably less severe.
- Health service demand is likely to be extremely high in our "plan for" scenario as we estimate that 336,000 people are likely to require hospitalisation, with a worst day demand of: 7,300 new patients, and 1,450 to 1,700 new intensive care unit (ICU) patients. This high demand risks overloading the hospital sector (given very limited surge capacity in NZ hospitals and ICUs at present).
- The peak week in our "plan for" scenario is 21 weeks after virus introduction (for uncontrolled spread), but successful control measures would postpone the date of the peak by some weeks to months.
- We estimate likely deaths to be between 12,600 and 33,600 people in our "plan for" scenario. This range can be considered relatively severe compared with our scenarios where lower transmissibility is modelled. It is also much more severe than the results of a case study where we take disease parameters from the largest outbreak outside of China ie, the Diamond Princess cruise ship outbreak and use these to extrapolate to all of NZ (see Appendix 2). Our "plan for" mortality estimates could also be over-estimates if treatment options improve and if a vaccine arrives later in 2020.
- As in previous epidemics and pandemics of infectious respiratory agents, severe disease burden is likely to fall unequally on Māori, Pacific peoples, and the elderly (see Appendix 3).

Background

This report provides numerical estimates and analytical overlay of potential New Zealand Covid-19 scenarios, based on modelling of infected case numbers from McVernon et al and using a NZ population of 4.96 million (unpublished report provided 21 February 2020).

Method

Graphics of models from McVernon et al were overlaid onto a grid. Data were extracted visually, and graphed in Excel to extract estimates of total infection and peak day numbers.

Assumptions

This report provides estimates for three potential epidemic scenarios for two levels of infectivity (R_0). All scenarios assume:

- Pre-symptomatic transmission as indicated in a Japanese study[1] (though the extent of this is still very uncertain).
- 48% of infections being asymptomatic (Japanese cruise ship data[2]);
- 20% of symptomatic infections requiring hospitalisation (ie, not in the "mild" category[3]).

The first, "plan for" infection scenario uses an R_0 of 2.2. This was the estimated reproduction number reported in Li et al 2020,[4] which we judge had the least methodological issues of measures to date.

We also provide numbers for an R_0 of 1.5. While an R_0 of 1.5 is lower than many early published estimates, it is consistent with the 2009 H1N1 influenza pandemic for NZ (mid-range out of 3 estimates[5]) and is more consistent with previous pandemics than values of 2.0 or higher (see Appendix 2).

For each scenario, we provide:

- Two alternative estimates for ICU demand, one based on a very large Chinese study indicating that 4.7% of cases are "critical";[3] and the other based on our estimate that 4% of symptomatic cases are likely to require ICU care.[6]
- Three alternative estimates for deaths, the first based on the WHO estimated case fatality risk (CFR) of 2% of symptomatic cases; the second based on our estimate that 34.1% of ICU admissions end in death[6]; and the third based on the 21 February 2020 CFR for cases outside China of 0.75%.[7] (The latter was prior to evidence suggestive of uncontrolled disease spread being plausible in Iran and Italy).

Interpretation and commentary

The large degree of uncertainty in the epidemiology of Covid-19 prevents us from providing narrow estimates for potential Covid-19 infections.

Our "plan for" scenario (which can be considered to be towards the "worse case" end of the outcome spectrum) sees 3,230,000 people, or 65% of the population, becoming infected with Covid-19, though we only expect 34% of the population (1,680,000) to experience symptoms. Nonetheless, even with these infection numbers, current estimates of the severity of the disease suggest health services are likely to be over-burdened, with 336,000 people being likely to require hospitalisation, including a peak demand day of 7,300 additional patients progressing to a stage requiring hospitalisation. Between 67,000 and 79,000 people are likely to need ICU treatment, with peak day demand of 1,450 to 1,700 additional ICU patients.

Our "plan for" scenario estimates total deaths between 12,600 and 33,600 people. These mortality estimates could be over-estimates if disease spread is slower (as per R_0 = 1.5), and if control measures are particularly successful; or they could still be under-estimates given hospitals and ICU overload will probably increase the case fatality risk. However, we note that this range is substantially higher than our estimate for the NZ mortality burden based on disease parameters for the largest outbreak outside of China ie, the Diamond Princess cruise ship outbreak (see Appendix 2). Extrapolating from that outbreak, we estimated 6,230 or 6,510 deaths in NZ if the same disease parameters applied in NZ as applied to this cruise ship. We expect transmission on the cruise ship was likely to have been very high, but the passengers also likely had a much higher average age than the NZ population. On the other hand, this cruise ship outbreak has been largely truncated via people being moved off the ship.

International data suggest that deaths will also typically be in those with co-morbidities: this topic can be addressed in a future report.

Figure 1: First 5 weeks of epidemic growth, showing all infections regardless of the degree of symptoms, for R_0=1.5, with 48 hrs pre-symptomatic transmission, by effectiveness of control measures (from McVernon et al)

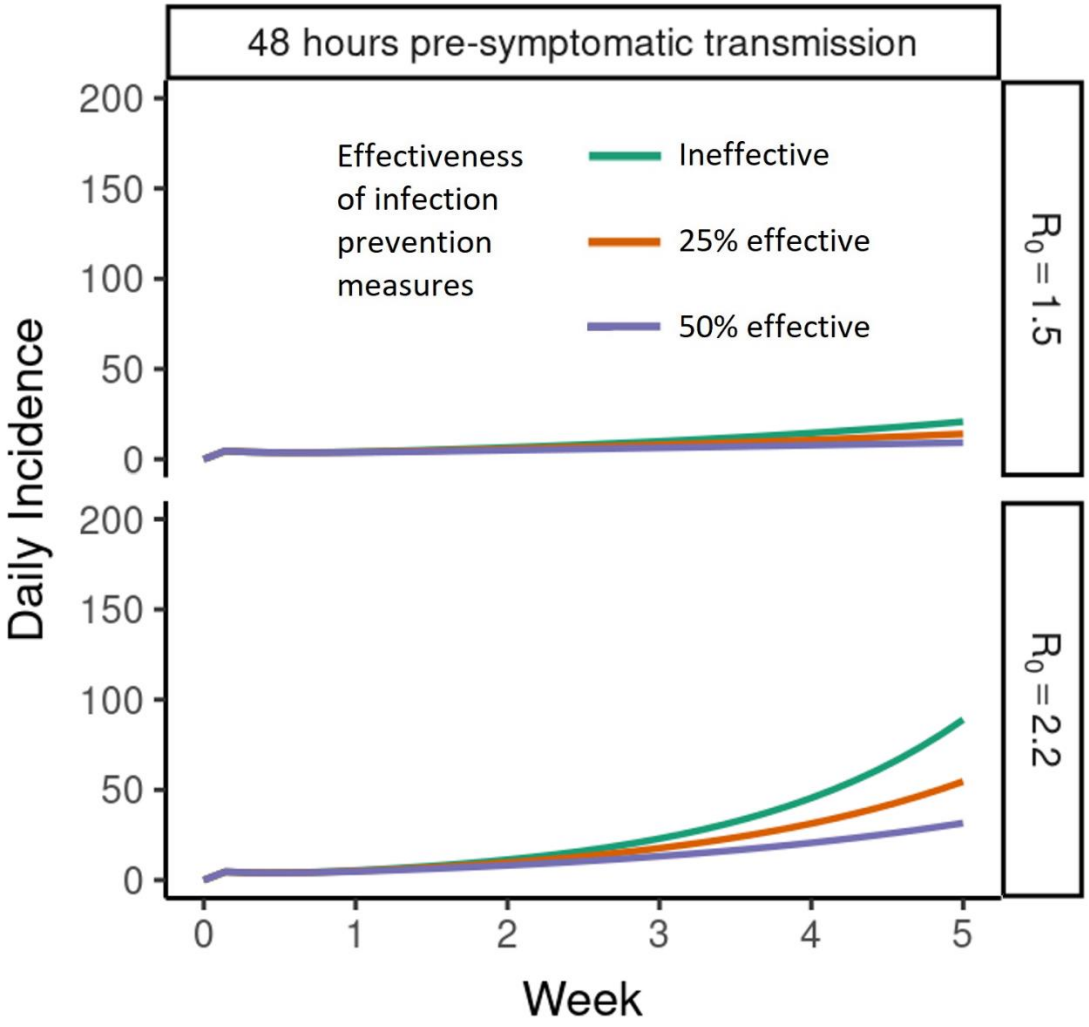

Figure 2: Epidemic curves showing ALL infections regardless of the degree of symptoms, for R_0=1.5 and R_0=2.2, with 48 hrs pre-symptomatic transmission, by effectiveness of control measures (from McVernon et al)

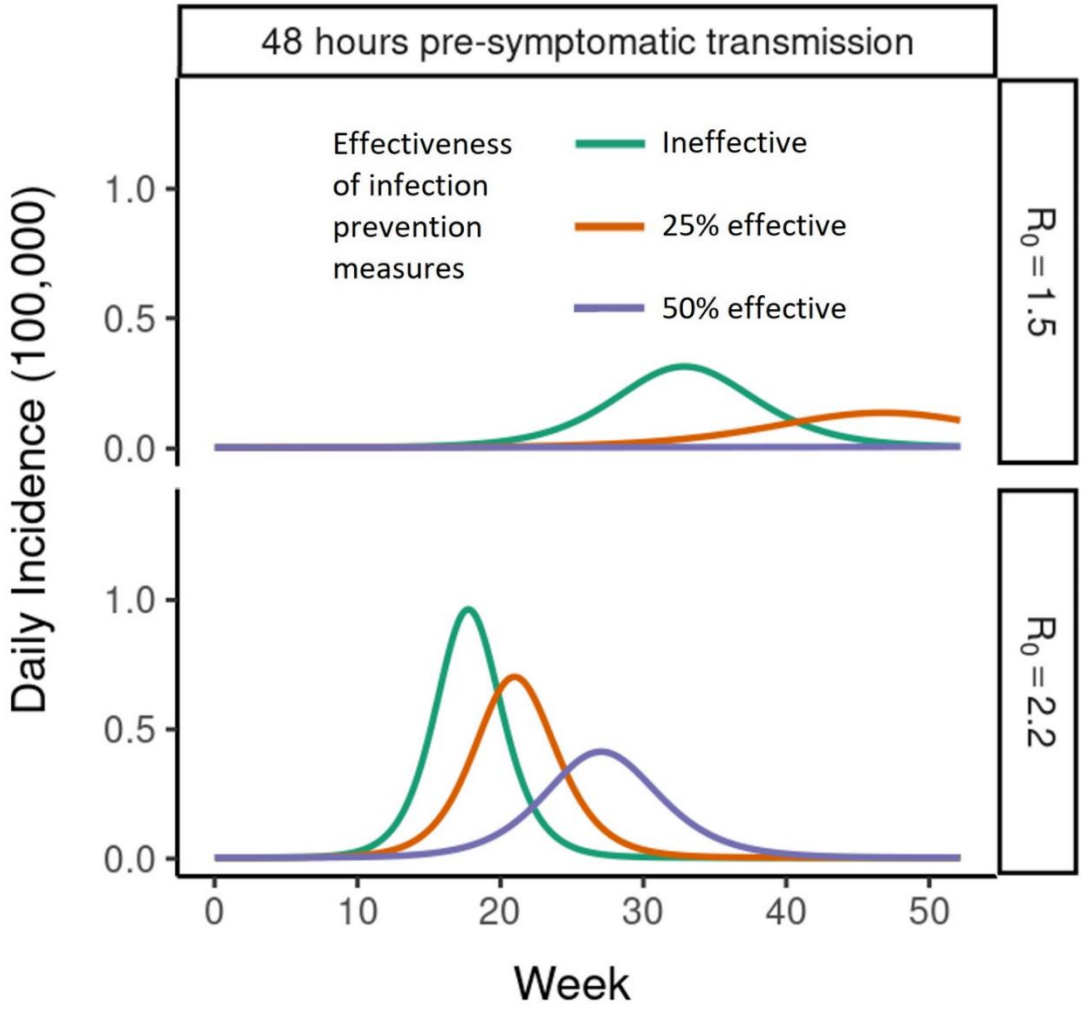

Table 1: Estimates for Covid-19 spread in NZ, 48 hrs pre-symptomatic transmission

R_0	1.5*		2.2		
Infection control effectiveness	**25%**	**0%**	**50%**	**25% ("plan for" scenario)**	**0%**
Peak day	Week 47	Week 33	Week 27	Week 21	Week 17
All infections					
Total	1,490,000	2,370,000	2,630,000	3,230,000	3,560,000
Proportion of NZ population (%)	30%	48%	53%	65%	72%
Worst day	13,500	31,000	42,000	70,000	96,000
Symptomatic cases					
Total	773,000	1,230,000	1,370,000	1,680,000	1,850,000
Worst day	7,000	16,000	22,000	36,000	50,000
Severe cases likely to require hospitalisation					
Total	155,000	246,000	273,000	336,000	370,000
Worst day	1,400	3,200	4,300	7,300	10,000
Cases likely to require ICU					
Total WHO (4.7%) Total UoO (4%)	36,000 31,000	58,000 49,000	64,000 55,000	79,000 67,000	87,000 74,000
Peak WHO (4.7%) Peak UoO (4%)	330 280	800 640	1,000 860	1,700 1,450	2,350 2,000
Deaths (CFR)					
Total WHO (2%) Total (ICU x 34%) Total (0.75)%	15,500 10,500 5,800	24,600 16,800 9,200	27,300 18,630 10,200	33,600 23,000 12,600	37,000 25,000 14,000
Peak WHO (2%) Peak (ICU x 34%) Total (O.75%)	140 100 50	320 220 120	430 290 160	730 500 270	1,000 680 380

* Figures for R_0=1.5 at 50% infection control are not precisely ascertainable from currently available graphical output from the modelling work by our Australian colleagues, more detail can potentially be made available in a subsequent report.

Limitations of this analysis

1. There is a high degree of uncertainty around all aspects of Covid-19 epidemiology. The R_0 may well be lower than our 2.2 "plan for" scenario value or it may be higher. Similarly, the CFR could be overestimated (due to missing mild cases in the denominator) or underestimated (due to the lag period for deaths to occur in ICU or from missed deaths).
2. The models do not adjust for potential seasonal effects, as these are complex. Disease spread is likely to be initially dampened if Covid-19 arrives in the warmer part of autumn or if case numbers remain low until late spring. Conversely, winter conditions would increase disease spread. The timing in the modelling for disease spread in NZ, did not consider potential super-spreading events. If these occurred it could truncate the timeline to the epidemic peak.
3. This analysis does not consider potential internal travel restrictions to prevent spread to another island or region (eg, when there is uncontrolled spread in the North Island – then protective sequestration could be applied to the South Island or of regions with limited road access such as the West Coast). Eg, the pandemic plan for Iceland identifies where road blocks would be set up to stop pandemic spread within the main island.
4. This analysis also does not consider protective sequestration of institutions such as retirement villages (ie, this was done for some institutions in the 1918 pandemic with some success). This intervention could impact on reducing the mortality burden since older people appear to have higher CFRs.
5. While this analysis uses such estimates as "25%" and "50%" control – it is possible that even more intense control is plausible eg, as per the above mentioned travel restrictions, protective sequestration and various other social distancing options. Also mass media campaigns by the government to promote staying at home when sick and to enhance hand and respiratory hygiene, could also reduce transmission. Indeed, the recent decline in new cases in China suggests that it is quite plausible that control measures could be more effective than the "50%" used in the modelling (albeit with some of the control measures in China being relatively severe).
6. Estimates for numbers of deaths assume people can receive necessary hospital and ICU treatment, but as health services will potentially be over-burdened, the CFR is likely to increase.
7. The models do not account for the potential discovery or development of more effective treatments. This innovation could reduce the number of cases needing hospitalisation and intensive care, and consequently reduce deaths.

Appendix 1: Case study of extrapolating from a large cruise ship outbreak of Covid-19 to NZ (if this pandemic reaches NZ and becomes uncontrolled)

An advantage of considering the outbreak on the Diamond Princess cruise ship is that it provides a clearer idea of the disease parameters and denominator populations – given the widespread testing of the crew and passengers. While attempts at quarantine were made on the cruise ship, this does not appear to have been fully effective and conditions on the ship are far more crowded than typical community settings (and indeed the ship crew were in dormitories and continued to have contact with passengers). Also the age distribution of passengers was probably older than the New Zealand population – and so this may increase the risk of more severe outcomes, including death. On the other hand, this cruise ship outbreak has been largely truncated via people being moved off the ship. Also the calculations below make no allowance for how overloaded hospitals and ICUs may not function normally when the pandemic peaks in a country like NZ, with the case fatality risk (CFR) being likely to increase in overloaded settings.

Table A1: A case study using parameters from a large cruise ship outbreak of Covid-19 and extrapolating to the NZ situation (if the pandemic reaches NZ and becomes uncontrolled)

Characteristic	Diamond Princess (cruise ship) data and estimates	Extrapolations to NZ	Comment
People with Covid-19 infection (including some asymptomatic infection)	634 people on 20 February 2020,[8] so this was 17.1% of the 3711 (crew and passengers)[2] initially on the ship	847,000	We used this proportion of cases (17.1%) for the NZ population (4.96 million population). Of note, however, is that some testing on the cruise ship may still be proceeding and so this proportion may increase with time. Another complexity in terms of final interpretation of the outbreak size, is that the denominator has started to change with evacuations from the ship. Of note is that those passengers with lab-confirmed COVID-19 were disembarked and transferred to an isolation ward at healthcare facilities.
Severity at level requiring ICU	2.1%	17,700	On 18 February when 454 cases were reported on the cruise ship: "The health ministry said 19 of the infected people were in serious condition, with some of them in intensive-care units."[9] So for this calculation we assumed half of these 19 people were in ICU.
Estimated deaths (extrapolating from ICU numbers)	5*	6050	We used the 34.1% from the typical case fatality in ICUs for severe respiratory conditions[10] (and for extra context and workings see: Wilson et al[6]).

Characteristic	Diamond Princess (cruise ship) data and estimates	Extrapolations to NZ	Comment
Estimated deaths using an out-of-China CFR	5*	6320	Out-of-China CFR as per a WHO report on 20 February (8/1073 = 0.75%.)[7]

* Indeed, three people from the cruise ship have actually died as detailed in a 24 February WHO Situation Report (where the number of cases/people testing positive had reached 695).

Appendix 2: Estimating the basic reproduction number (R_0) for COVID-19 in New Zealand

The basic reproduction number R_0 represents the average number of secondary infections per case in a fully susceptible population. Future projections of clinical burden and impact are highly sensitive to the value of R_0 selected for modelling as this value drives the proportion of the population infected. Estimating the value of R_0 is challenging, however, because estimates of R_0 are themselves sensitive to both measurement error and environmental conditions, particularly during an evolving pandemic. Measures of R_0 in a given population will strongly reflect the sociodemographic characteristics, public health interventions, climate, and geography of that population.[5 11]

Because there have been relatively few cases outside China (and none to date in New Zealand), most of the currently available estimates are based on cases occurring in China during the early stages of the epidemic. Estimates of R_0 calculated in this way vary from 2 to 5.[12]

R_0 is consistently overestimated in the early phases of a pandemic, for a range of reasons.[13] Taking this bias into account together with contextual differences, it is highly likely that the true R_0 in New Zealand would be substantially lower than estimates from Chinese studies. Reasons for the difference include:

- Higher levels of crowdedness in Chinese cities compared with New Zealand
- Initial overestimation of R_0 e.g. because of changes in reporting rates.[12]
- Greater population susceptibility to infection from existing compromised respiratory health due to poor air quality from air pollution and high smoking rates in China.

Table A2 shows estimates of R_0 in the New Zealand population during respiratory virus pandemics. Values of R_0 have been consistently in the range 1 to 2, with one slightly higher early estimate.

Table A2. Estimates of the reproduction number in New Zealand during previous respiratory virus outbreaks.

Estimated R_0 (95% CI)	Pandemic	Source	Comment
1.96 (1.80 – 2.15)	2009 H1N1	Nishiura et al., 2009[14]	Preliminary estimate
1.25 (1.07 – 1.47)	2009 H1N1	Roberts et al., 2011[15]	Updated estimate
1.55 (1.16 – 1.86)	2009 H1N1	Paine et al., 2010 [16]	Peak value
1.34 (1.27 – 1.38)	2009 H1N1	Opatowski et al., 2011[11]	Confirmed cases
1.2 – 1.8	1918 pandemic	Wilson et al., 2012[17]	In community settings

These New Zealand estimates are also consistent with global estimates of R_0 from previous pandemics; retrospective estimates of R_0 from systematic reviews and meta-analyses include:

- 1.2 to 1.8 in eight Southern Hemisphere countries for 2009 H1N1 pandemic influenza[11]
- 1.65 (IQR 1.53 – 1.70) in the 1957 influenza pandemic[5]
- 1.80 (IQR 1.47 – 2.27) in the 1918 influenza pandemic.[5]

During its early stages, Severe Acute Respiratory Syndrome (SARS) was estimated in modelling to have an R_0 of 2.2 – 3.6, but data from the first 205 probable cases in Singapore indicated an $R_0 < 1$

from approximately the third week onwards.[18] Mercer et al list several similar examples of this trend.[13]

Summary

Currently available estimates of R_0 are uncertain because the transmission characteristics of this novel virus are still somewhat unclear. The "plan for" value of $R_0 = 2.2$ indicates the current consensus around scenarios for planning. However, estimates generated by data from China are likely to introduce substantial overestimation of impacts in the New Zealand population. For this reason, scenarios based on a lower value of R_0 are also presented for comparison purposes. The value of $R_0 = 1.5$ included in the models presented here is consistent with a) the lower limit of estimates from China, b) estimated R_0 in other New Zealand pandemics, and c) global estimates from other pandemics that were generated after the earliest stages of the event.

Appendix 3: Potential age and ethnic distribution of Covid-19 health impacts (assumed uncontrolled spread occurs in NZ).

Key messages

- **The numbers presented here represent potential future scenarios rather than predictions and will be strongly influenced by the transmissibility and severity of the Covid-19 pandemic when it reaches New Zealand.**
- If Covid-19 follows the same patterns as previous pandemics, there may be a relatively high and heavily unequal hospitalisation and mortality burden on Māori and Pacific populations.
- Elderly are particularly at risk, and Māori and Pacific elderly even more so, and from younger ages.
- Nevertheless, these poor outcomes are modifiable ie, if the entry of Covid-19 to NZ is delayed, if there are successful interventions that substantially reduce transmission in Māori and Pacific communities (eg, intensive hand and respiratory hygiene messages and social distancing interventions such as reducing public gatherings and closing schools) or even more radical measures are used such as protective sequestration of communities.

The numbers in this Appendix are based on the "plan for" scenario of R_0=2.2, 48hrs pre-symptomatic transmission, with 25% effective infection control measures. We use the Chinese data (CCDC) 2% case fatality risk[3] as our basis for age-specific deaths, and we treat the age distribution of cases in that report as the age distribution of hospitalisations.

Ethnic distribution

We assume ethnic inequalities in mortality will be similar to those in the 2009 Influenza A(H1N1) pandemic, ie, that the risk of hospitalisation was 5 times higher for Māori and 7 times higher for Pacific peoples,[19] while the risk of death was 2.6 times higher for Māori (95%CI: 1.3 – 5.3) and 4.6 times higher for Pacific peoples (95%CI: 2.0 – 7.2) than for NZ European/Other.[20]

The estimated ethnic distribution of the hospitalisation and mortality burden under the "plan for" scenario is shown in Table A3-1. Numbers do not include any age-standardisation.

Table A3-1. Estimated ethnic distribution of Covid-19 hospitalisations and deaths, "plan for" scenario.

Ethnic group	Hospitalisations		Deaths	
	n	Pop %	n	Pop%
Māori	128,230	16.4%	9,240	1.2%
Pacific	92,190	23.1%	8,360	2.1%
NZ European/Other	115,580	3.3%	16,000	0.5%
Total	336,000	6.8%	33,600	0.7%

Age distribution

Our estimates of the age distribution of deaths (Table A3-2) are based on CCDC reports of case fatality risk by age, and the Chinese population age structure estimated from the CIA World Factbook, adjusted to the New Zealand population and the projected number of deaths.

Table A3-2. Estimated age distribution of Covid-19 mortality, "plan for" scenario.

Age group (years)	Hospitalisations		Deaths	
	n	Pop %	n	Pop %
0-9	3,132	0.5%	0	0.0%
10-19	4,173	0.7%	19	0.0%
20-29	21,193	3.0%	102	0.0%
30-39	47,807	7.4%	282	0.0%
40-49	43,689	7.0%	482	0.1%
50-59	65,690	10.4%	2,122	0.3%
60-69	63,542	12.2%	5,689	1.1%
70-79	41,181	11.9%	8,155	2.3%
80+	45,593	25.2%	16,750	9.3%
Total	336,000	6.8%	33,600	0.68%

Age and ethnic distribution

The age and ethnic disaggregated figures which follow are based on multiple interpolations and extrapolations. As these numbers are a number of steps removed from their bases, they can only be very rough estimates. Numbers for Pacific peoples over the age of 60 were particularly unstable. The key message from these numbers is that the mortality burden is likely to fall particularly heavily on older (aged ~60+) Māori and Pacific peoples

NZ European/Other

Estimated NZ European/Other deaths under the "plan for" scenario are shown in Table A3-3.

Table A3-3. Estimated NZ European/Other age distribution of Covid-19 hospitalisations and mortality, "plan for" scenario.

Age group (years)	Hospitalisations		Deaths	
	n	Pop %*	n	Pop %
0-9	1,021	0.2%	0	0.0%
10-19	1,353	0.3%	8	0.0%
20-29	6,666	1.4%	42	0.0%
30-39	13,426	3.5%	104	0.0%
40-49	14,137	3.3%	205	0.0%
50-59	23,265	4.9%	987	0.2%
60-69	23,382	5.7%	2,748	0.7%
70-79	16,539	5.6%	4,300	1.4%
80+	15,788	11.8%	7,615	5.7%
Total	115,580	3.3%	16,009	0.46%

* Percentages are row percentages (with the denominator being the population in that age-group).

Māori and Pacific peoples

There are difficulties extrapolating mortality distributions from the Chinese example to the Māori and Pacific populations, who not only have a very different population age structure, but also have different life expectancies. Comparing population mortality rates, in ordinary circumstances, the mortality risk of a Māori person aged 60 years, for example, is roughly equivalent to the mortality risk of a NZ European person aged 70 years.

Since Covid-19 mortality appears to heavily reflect age-related vulnerability, we have calibrated Māori and Pacific age-specific mortalities to NZ European/Other age-specific mortality when calculating estimated ethnic-group specific age-related mortality. Calibrating age bands reduces the starting age of the upper "80+ years" age band to 74 years for Māori and 73 years for Pacific peoples.

Following this calibration, estimates for age-related mortality for Māori and Pacific peoples under the "plan for" scenario are shown in Tables A3-4 and A3-5. In Table A3-5 the 60+ and 73+ age bands were combined, as low population numbers in the top band resulted in an unstable estimate.

Table A3-4. Estimated Māori age distribution of Covid-19 hospitalisations and mortality, "plan for" scenario.

Age group (years)	Hospitalisations		Deaths	
	n	Pop %	n	Pop %
0-9	2,475	1.5%	0	0.0%
10-19	3,030	1.9%	10	0.0%
20-29	17,305	13.5%	68	0.1%
30-39	17,945	20.8%	144	0.2%
40-49	25,404	30.7%	598	0.7%
50-59	27,412	36.0%	1,788	2.3%
60-73	21,472	35.0%	3,098	5.0%
74+	13,186	74.3%	3,529	19.9%
Total	128,230	16.4%	9,236	1.2%

Table A3-5. Estimated Pacific age distribution of Covid-19 hospitalisations and mortality, "plan for" scenario.

Age group (years)	Hospitalisations		Deaths	
	n	Pop %	n	Pop %
0-9	1,949	2.1%	0	0.00%
10-19	2,266	2.8%	10	0.0%
20-29	14,393	20.2%	76	0.0%
30-39	14,760	30.5%	158	0.3%
40-49	18,330	45.2%	575	1.4%
50-59	17,935	53.0%	1,559	4.6%
60+	20,099	59.8%	4,739	14.1%
Total	92,190	23.1%	8,355	1.2%

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