Appendix 1: COVID-19 surveillance and epidemiology in New Zealand

Aotearoa New Zealand has a COVID-19 surveillance strategy, with multiple surveillance systems operated by Manatū Hauora – Ministry of Health (MoH), Te Whatu Ora – Health New Zealand and the Institute for Environmental Science and Research (ESR).[89] These systems provide data on different categories of COVID-19 infection and a range of other key measures such as vaccination coverage. Results are presented on the Te Whatu Ora – Health New Zealand website.[18]

Here we present an analysis of COVID-19 surveillance data starting from 2020 up to the time of writing in mid-2023. The data for this analysis were obtained from the MoH[4] and ESR.[90] All data were extracted on 3 July 2023.

COVID-19 cases in the community

COVID-19 is a notifiable condition for diagnosing doctors, with cases confirmed by laboratory-based PCR testing or self-reported rapid antigen tests (RATs).[91] Since early 2022 members of the public have had widespread free access to RAT kits for testing themselves and people they are caring for. They have been required to report positive test results online.[92]

Case numbers remained relatively low during the elimination and suppression stages of the pandemic response but increased markedly following widespread transmission of the Omicron variant from February 2022 onwards (Figure 2). After January 2023, self-reported cases reached their lowest 7-day moving average of 1,132 per day on 11 February 2023. The numbers subsequently rose, reaching a moving average of 2,143 per day on 17 April 2023 before decreasing again as part of New Zealand's fourth pandemic wave.

COVID-19 hospitalisations and ICU admissions

Hospitals report diagnosed COVID-19 cases to the MoH, including admissions to intensive care units (ICUs). There is an international system for coding COVID-19 cases.[93]

During 2023, new weekly admissions increased from 132 for the week ending 19 February to a peak of 343 for the week ending 23 April 2023 before declining slowly (Figure 3).

COVID-19 deaths

Deaths linked to COVID-19 are reviewed by coding staff in the MoH who distinguish those that are attributed deaths (where COVID-19 was considered the underlying or contributing cause of death), and those that are unrelated cases, which are removed.[94] The MoH also reports all

Figure 2: COVID-19 cases in New Zealand, 7-day moving average of daily cases, from January 2020 to June 2023. Source: MoH.[4]

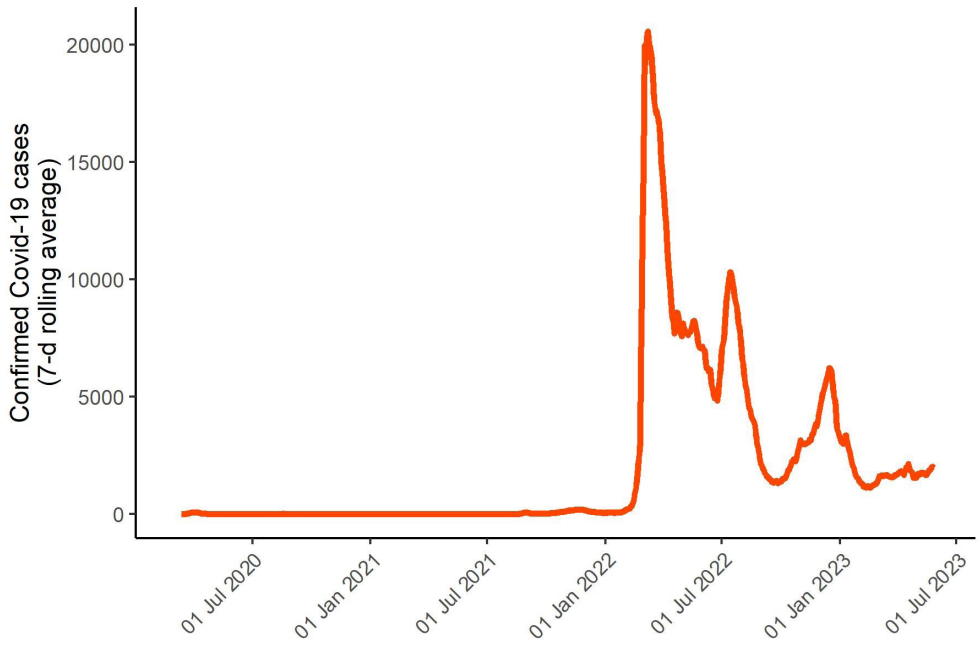


Figure 3: COVID-19 hospitalisations in New Zealand, weekly total, from January 2020 to June 2023. Source: MoH.[4]

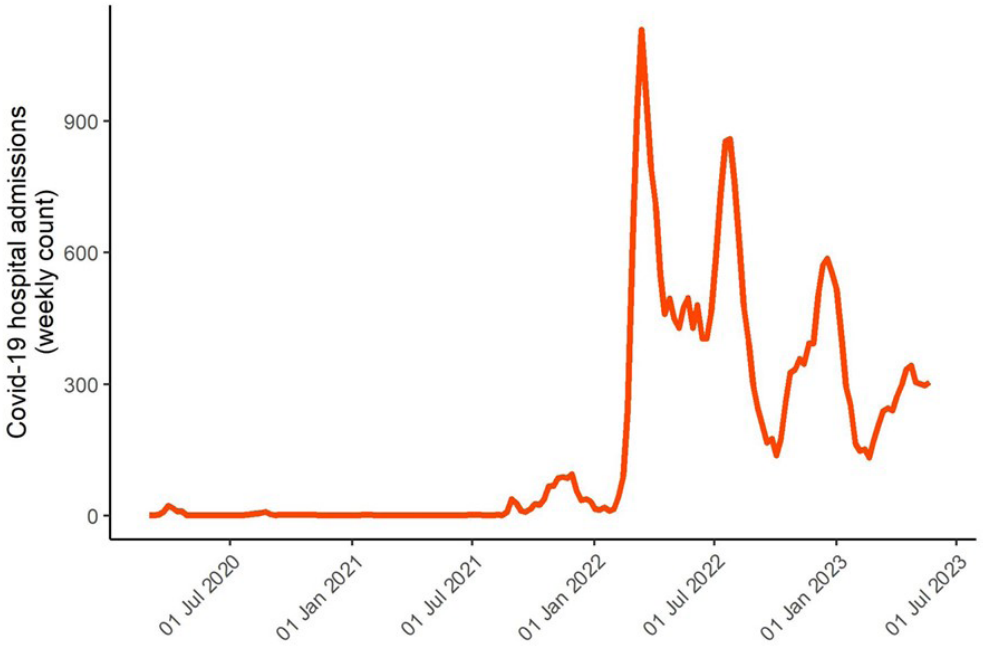
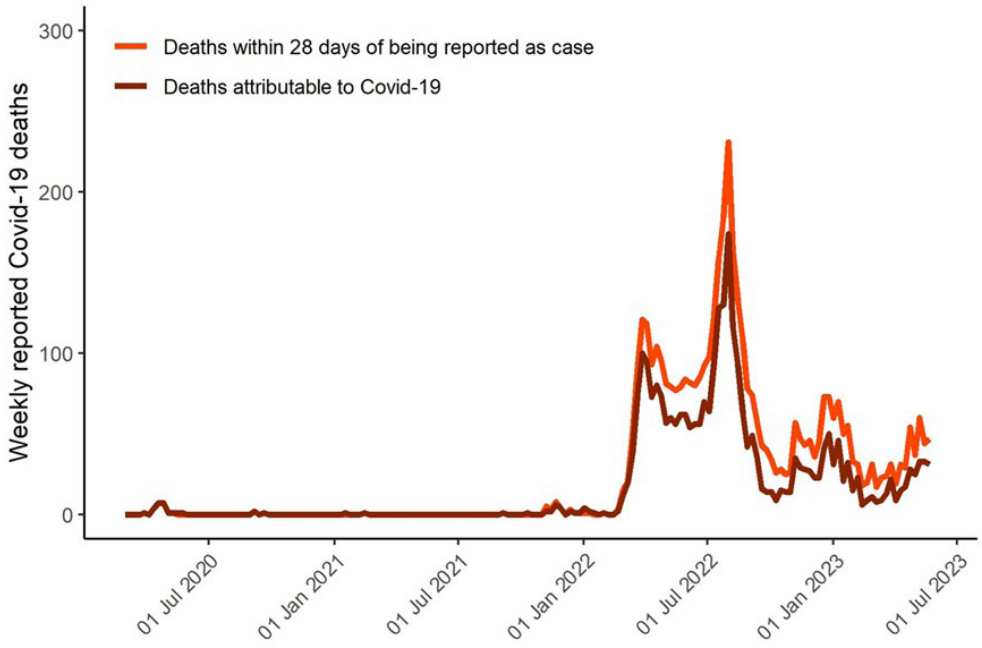


Figure 4: COVID-19 deaths in New Zealand, weekly total, from January 2020 to June 2023. Source: MoH.[4]



deaths within 28 days of COVID-19 infection as a separate category. The COVID-attributed measure may under-estimate mortality, which is substantially raised for at least 2 years following COVID-19 infection, particularly for people reporting long COVID.[9,16,17]

In the second quarter of 2023, deaths attributable to COVID-19 appeared to peak at 33 for the week ending 7 May 2023. Deaths within 28 days of being reported as a case appeared to reach a peak of 60 deaths that week (Figure 4).

Wastewater testing for COVID-19

Specimens are collected from sewerage systems at sites across New Zealand and tested for SARS-CoV-2 RNA.[75] These data are presented on the ESR Wastewater Surveillance Dashboard.[95] Wastewater sites are selected based on several factors including population and geographic coverage. New sites may be added over time and/or sampling may reduce in frequency or cease for other sites.

Results of wastewater testing showed a similar series of four pandemic waves during the 2022–2023 period that corresponded to waves of infection detected through other forms of surveillance. These testing results are likely to provide a relatively consistent indicator of COVID-19 infection levels in the community as they do not depend on levels of testing and reporting by members of the public.

During 2023, this testing showed a rise in SARS-CoV-2 RNA levels in wastewater from a low point of 1.5 million genome copies per person per day on 5 February 2023 to 4.4 million genome copies per person per day on 16 April 2023 before a decline in detections (Figure 5).

Genomic surveillance of COVID-19

Specimens obtained from cases and from wastewater undergo whole genome sequencing and analysis.[69] Results are regularly updated on the ESR COVID-19 Genomics Insights Dashboard (CGID) (Figure 6).[3]

These data show that initially there was a series of dominant Omicron subvariants associated with each wave of infection—notably BA.1/BA.2 with the first wave in 2022, and BA.4/BA.5 with the second wave. More recently the pattern has been characterised as a "swarm" or "soup" of multiple subvariants.[96] New Zealand had a mix of BA.2.75, BA.5, CH.1.1 and BQ.1.1 subvariants associated with the third wave in late 2022. The most recent (fourth) wave in 2023 coincided with a rise in XBB subvariants, which became dominant in human cases and wastewater samples.[3,97] These subvariants had also been associated with waves of infection overseas, notably in Singapore.[98]

Excess mortality

New Zealand sustained low excess mortality through the first 2 years of the pandemic until

Figure 5: COVID-19 wastewater detections and new cases in New Zealand, by day, from January 2020 (cases) and June 2021 (wastewater) to June 2023. Sources: ESR,[90] MoH.[4]

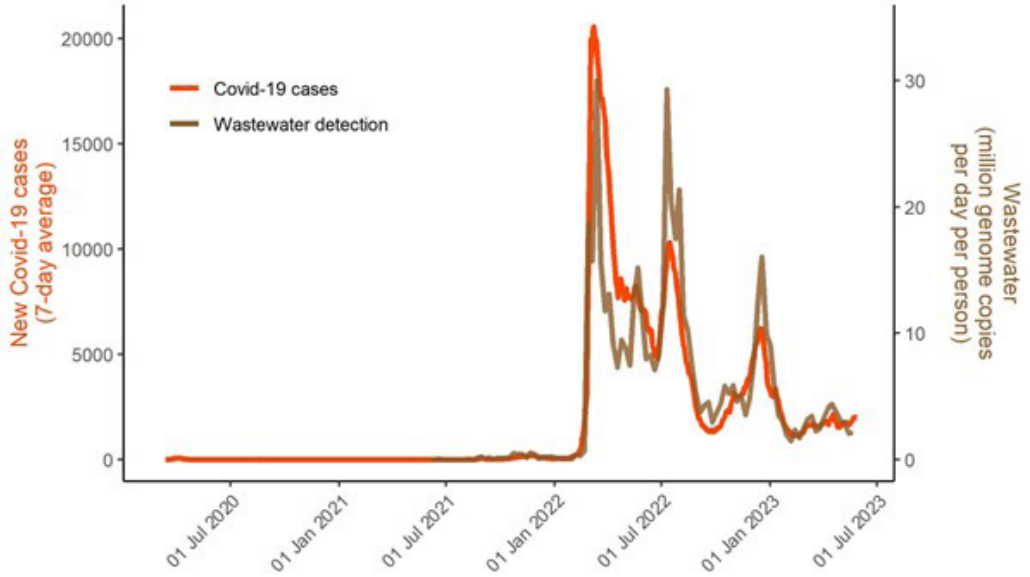


Figure 6: COVID-19 variants and subvariants isolated in New Zealand (including from Managed Isolation and Quarantine at the border), by day, February 2020 to June 2023. Source: ESR.[99]

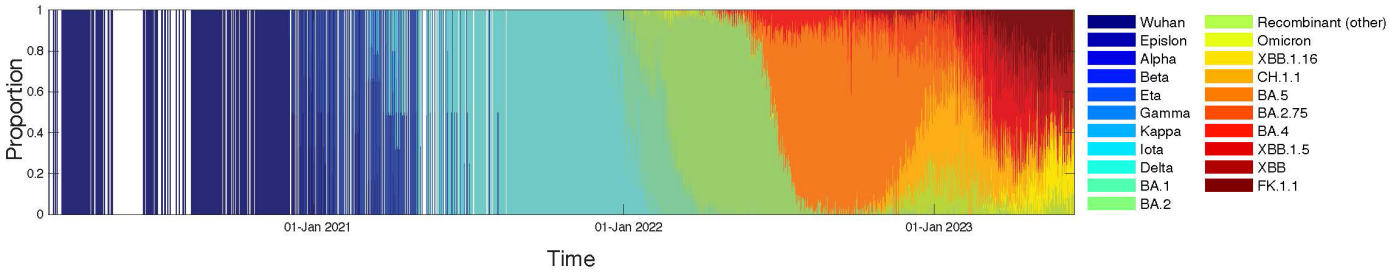
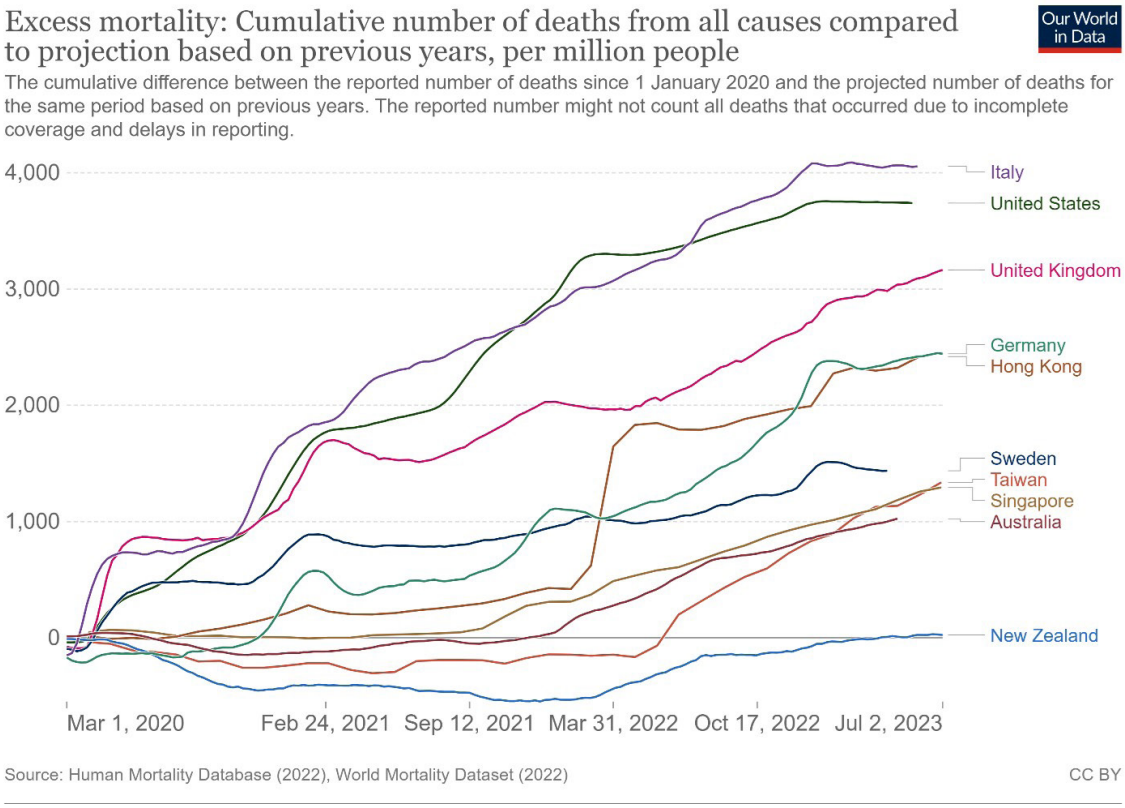


Figure 7: Cumulative excess mortality, expressed as deaths per million people from all causes compared to projected numbers based on previous years, for New Zealand and a selection of other high-income jurisdictions up to June 2023. Source: OWD.[102]



COVID-19 circulated widely in 2022.[62] Several organisations including WHO,[100] The Economist magazine[101] and Our World in Data (OWD)[102] have generated excess mortality estimates. These estimates use similar approaches of comparing total mortality since the start of the pandemic (January 2020) with "expected mortality" based on the pattern of the preceding years (OWD uses the preceding 5 years, 2015–2019[103]). The OWD site shows New Zealand is one of only four remaining countries globally that are estimated to have excess mortality close to zero at the time of writing (Figure 7). The other jurisdictions (Luxembourg, Antigua and Barbuda, and Seychelles) all have small populations (<0.7 million). The COVID-19 pandemic appears to be driving an increase in overall mortality in many countries, including in younger age groups,[104] but these totals do not distinguish between impacts of the infection itself and other factors such as reduced access

to healthcare or suppression of other infectious diseases such as influenza.

If New Zealand (resident population 5.185 million in 2022) had experienced the cumulative excess mortality of the US (3,739.3 per million) then we would have had around 19,390 excess deaths up to the end of June 2023. With the United Kingdom (UK) excess mortality (3,164.8 per million), we would have had around 16,410 excess deaths, or using the experience of Sweden (1,436.3 per million) we would have had 7,450 excess deaths. New Zealand's excess was varying around zero in mid-2023 (122 at the time of writing).

Globally, COVID-19 is likely to have been the third leading cause of death in the world for the last 3 years (2020–2022).[105]

Longer-term effects of COVID-19 on population health

COVID-19 is a multi-organ disease with mechanisms of effect that include immune dysregulation, autoimmunity, abnormal neurological signalling and damage to small blood vessels (endothelial dysfunction) causing microclots.[106,107,108] Endothelial dysfunction is considered to be the central underlying mechanism of acute- and post-acute COVID-19 disease.[109]

These cell- and tissue-level impacts may manifest as a post-acute viral syndrome (syndromic long COVID)[110] similar to that caused by a range of other infections.[107,111] Alternatively, health impacts may follow a more organ-specific pattern, presenting as heart attacks, new-onset diabetes including type 1 diabetes in children, decreased lung function, cognitive dysfunction and others.[106,112–115] These types of health conditions do not appear to differ markedly from variant to variant, but the risk is lower in Omicron infections compared with earlier variants and there is evidence of a protective effect of vaccination.[116] Robust evidence of the effect of multiple Omicron reinfections is not yet available.

There appears to be a wide overlap between syndromic and non-syndromic presentations, with over 200 symptoms described to date. Because only a little over 3 years of observation time of this virus is possible, we can expect that different types of longer-term impacts may resolve or emerge in future. For example, there are arguments both for and against a role for COVID-19 in causing or exacerbating cancers.[117]

In this paper we use the term "long COVID" to cover all sequelae of COVID-19 infection. This term includes the alternative names of post-COVID conditions, long-haul COVID, post-acute COVID-19, long-term effects of COVID, chronic COVID and post-acute sequelae of SARS CoV-2 infection (PASC).

Estimating the incidence and prevalence of long COVID in populations is challenging. Studies of syndromic long COVID (i.e., reported symptoms) following infection include the following recent examples that show the wide range of findings from different study designs and measurement approaches. Each of the following cohort designs has potential to both under- and over-estimate the incidence.

- The WHO's current (2023) estimate is that 10–20% of people experience health effects that persist or manifest themselves more than 3 months after recovery from the initial episode; this estimate has not been updated for more recent variants.[8]
- The UK's Office for National Statistics (ONS) estimates that 2.4–4% of adults and 0.6–1% of children report having long COVID 12–20 weeks after infection (and 1.6–2.8% of adults and 0.4–0.6% of children reported having "limited daily activities").[118] The ONS survey is high quality, and the sampling frame and design are extremely robust. There are some measurement aspects (e.g., the timing and questionnaire) in the above estimate that may under-count long COVID.
- The Long COVID in Children and Young People (CloCK) study's most recent estimate for 11–17-year-olds (Omicron; prospective test-negative design; n=886; 5.9% survey response rate) was 12.1% of respondents (first positives), 16.1% (reinfected) and 4.8% (always tested negative) at both 3- and 6-months post-test. The analysis did not show a significant difference in prevalence of long COVID symptoms between first infections and reinfections.[119]
- The most recent estimate for adults from the National Institutes of Health's Researching COVID to Enhance Recovery (RECOVER) Initiative was that 10% (95% confidence interval [CI], 8.8–11%) of study participants were PASC-positive at 6 months (prospectively measured) based on a composite score of a small number of selected symptoms that aimed to optimise sensitivity and specificity. The authors reported that "*among participants with a first infection during the Omicron era, PASC*

frequency was higher among those with recurrent infections" and they reported a "modest reduction" in PASC among vaccinated participants compared with unvaccinated.[120]
- The US Census Bureau (Household Pulse Survey; April/May 2023) estimates that 5.6% (95% CI, 5.3–5.9) of all adults are currently experiencing long COVID.[121]
- In a 2021 New Zealand survey, 22% of respondents who had had a confirmed COVID-19 infection reported symptoms of long COVID.[11] This study had a 12% response rate and recruited participants who tested positive before December 2021, so these results reflect pre-Omicron variants and, in some cases, pre-vaccination infections.

Even at the lowest end of the prevalence range listed here, the impact of COVID-19 on long-term public health is highly concerning. A major reason is that population exposure is high, and continuing, resulting in infections and reinfections that will ultimately be experienced by most people. The long-term trajectory of this disease burden is very hard to predict given the multiple unknown factors. But the precautionary principle suggests we should take a cautious approach and assume the long-term health impact is at least as high as the mid-range estimates are suggesting and respond accordingly, at least until we have high-quality evidence to the contrary.

Therapeutic strategies to prevent and treat long COVID are an active area of research. A recently reported randomised controlled trial tested outpatient treatment options in a cohort of adults with overweight or obesity.[122] Randomisation took place between 30 December 2020 and 28 January 2022 with a 10-month follow-up. Only one treatment, metformin, showed a significant improvement over placebo in cumulative incidence of long COVID at day 300. The incidence of long COVID was 6.3% (95% CI, 4.2–8.2) in participants who received metformin and 10.4% (7.8–12.9) in those who received identical metformin placebo (hazard ratio [HR], 0.59; 95% CI, 0.39–0.89; p=0.012). Among the vaccinated subgroup, incidence was 6.1% and 7.2% respectively in the treatment and control groups (HR, 0.85; 95% CI, 0.46–1.57). This finding also provides additional therapeutic validation of long COVID as a clinical condition to add to the symptom data reported by those living with long COVID[123] and the large literature reporting radiological and immuno-pathological evidence of end-organ damage.[108]

Vaccination surveillance

The systems for surveillance of key aspects of vaccination include vaccine coverage surveillance conducted by the MoH[58] and vaccine adverse event surveillance conducted by MedSafe.[61]

Vaccination coverage data provide multiple measures of the time distribution of vaccination doses (Figure 8) and who is receiving vaccines, including breakdowns by place and person (age, ethnicity).[58]

Adverse event surveillance also includes multiple measures of vaccine safety. For example, it shows that the risk of sudden death in the 21 days following receipt of the main COVID-19 vaccine used in New Zealand (the Pfizer/BioNTech mRNA vaccine Comirnaty) is reduced to about half of the expected background rate.[61] This reduction is likely due to a *healthy vaccinee effect* where healthy people are preferentially vaccinated compared with those who are unwell with comorbidities. Serious adverse events are rare following vaccination. Of the deaths that occurred following administration of the Pfizer vaccine up to 30 November 2022, two were determined by the coroner to be due to myocarditis, of which one was likely vaccine-induced myocarditis and for one a link to the vaccine could not be excluded.[61] A total of around 11.9 million doses were given during this time.[61]

Other forms of COVID-19 surveillance

There are multiple additional forms of surveillance that have been used to better understand the COVID-19 pandemic and response. Some surveillance makes use of existing data gathering processes such as use of Google Global Mobility data.[124] Other surveillance is specifically designed to gather data on COVID-19. An example is behavioural risk factor surveillance conducted by the MoH.[125]

Stringency of COVID-19 restrictions in New Zealand

The OWD site also reports the level of COVID-19 restrictions for jurisdiction across the globe. They use the Oxford Stringency Index, a composite based on nine measures (school closures; workplace closures; cancellation of public events; restrictions on public gatherings; closures of public transport; stay-at-home requirements; public information campaigns; restrictions on internal movements; and international travel controls). The index is

Figure 8: Count of vaccinations administered by week from the COVID-19 Immunisation Register. Source: MoH.[58]

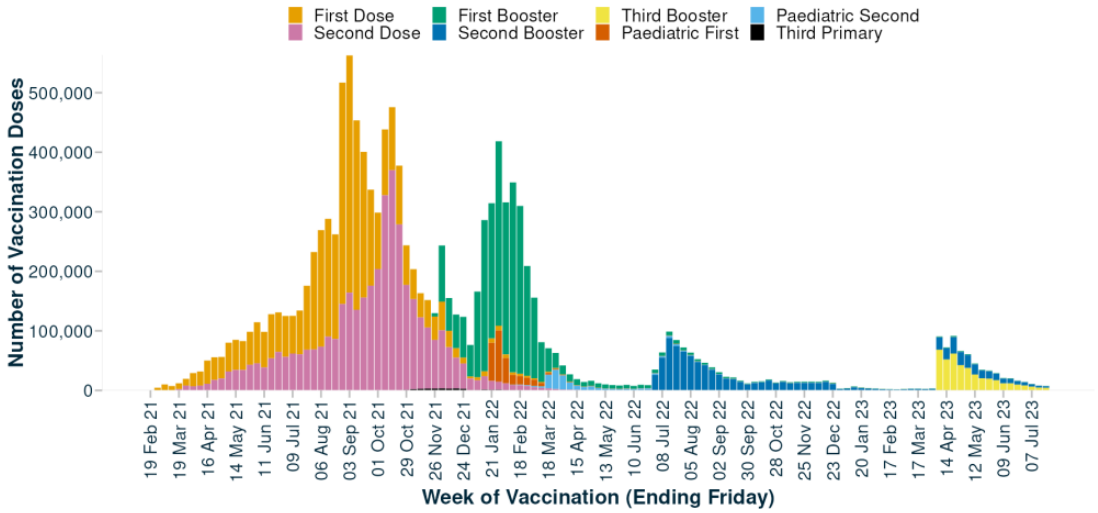
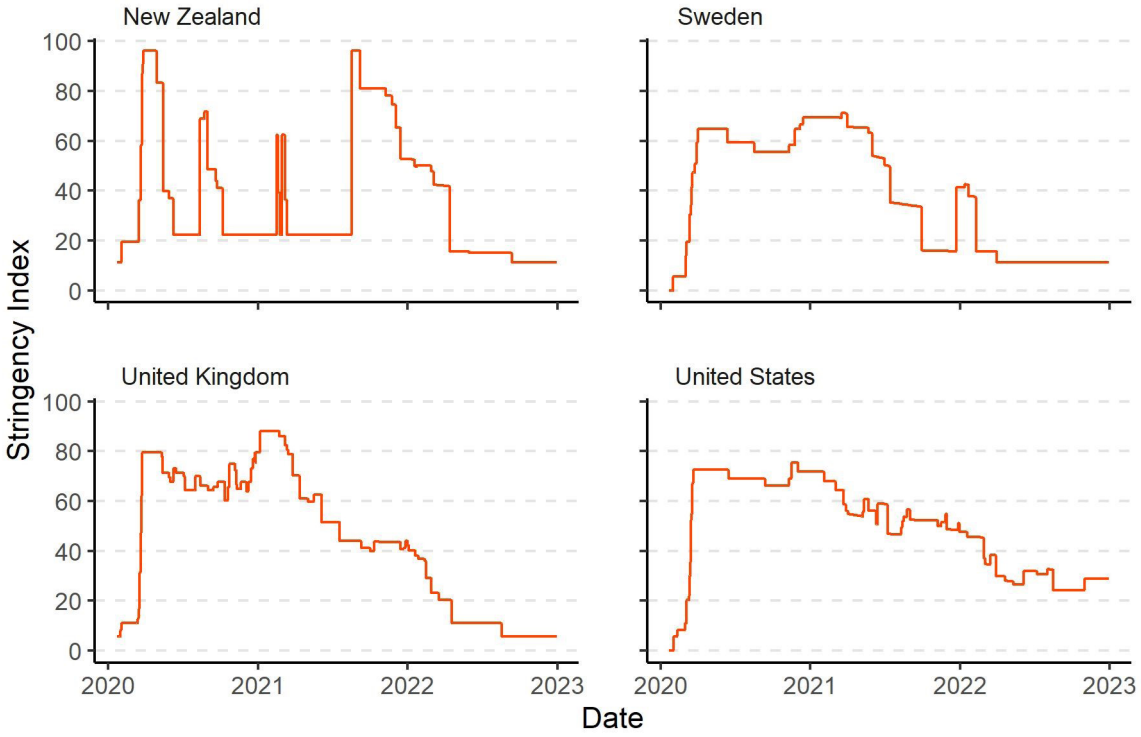


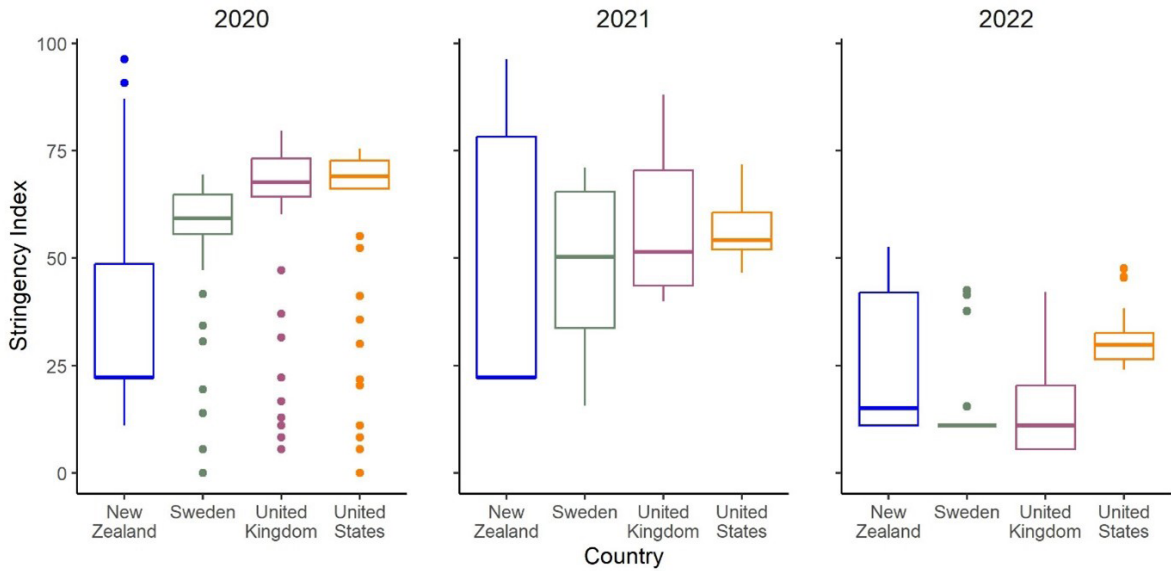
Figure 9: Level of COVID-19 restrictive policies during the pandemic in selected countries (22 January 2020 to 31 December 2022). The Stringency Index is based on nine response indicators including school and workplace closures and travel bans. Source: OWD.[102]



Appendix Table 1: Proportion of days per year spent above policy restriction thresholds (22 January 2020 to 31 December 2022; 1,075 days total). Source: OWD.[102]

Country	Percentage of days each year spent below/above Stringency Index thresholds (%)											
	2020				2021				2022			
	<30	≥30	≥50	≥70	<30	≥30	≥50	≥70	<30	≥30	≥50	≥70
New Zealand	59.4	40.6	21.2	17.4	57.0	43.0	40.3	29.6	72.1	27.9	14.2	0.0
Sweden	14.5	85.5	81.7	0.0	23.3	76.7	52.3	3.8	89.3	10.7	0.0	0.0
United Kingdom	16.2	83.8	82.6	37.1	0.0	100.0	54.5	27.7	87.7	12.3	0.0	0.0
United States	14.5	85.5	84.3	38.3	0.0	100.0	80.3	9.0	55.9	44.1	0.0	0.0

Figure 10: Median COVID-19 policy stringency for selected countries. Boxplots detail median, inter-quartile range, range and outliers (based on daily data, 22 January 2020 to 31 December 2022; 1,075 days total). Source: OWD.[102]



scaled from 0–100, with higher values indicating a greater level of restrictions.[126]

Figures 9 and 10 and Appendix Table 1 show a comparison of New Zealand with three other countries (a full range of country comparisons can be generated on the OWD website). This comparison shows how New Zealand used restrictions, such as stay-at-home orders (lockdowns), for relatively short periods during the elimination phase to "stamp out" COVID-19 outbreaks before returning to periods with few restrictions except at borders. Then during the suppression phase, it used them for a sustained period at a less intense level to minimise the transmission of COVID-19, before using them at a lower intensity during the mitigation phase.

By comparison, countries such as the US, UK and Sweden used moderate to high levels of restrictions continuously for much of the first 18 months of the pandemic to suppress transmission to minimise the health burden and avoid overwhelming health services. The net effect was markedly less time living with restrictions (≥50 stringency) in New Zealand during the first 2

years of the pandemic, particularly in 2020. All countries greatly reduced controls following arrival and spread of the Omicron variant in late 2021 or early 2022.

Reassuringly for New Zealand, periods of relatively high stringency of pandemic controls in 2000 and 2001 were associated with negative excess mortality, i.e., low and decreasing mortality (Figure 7). Excess mortality increased in 2022 corresponding to less stringent controls and high COVID-19 infection. This evidence suggests COVID-19 infection has been the main cause of an increase in excess mortality in 2022 rather than the effects of pandemic control measures and vaccination.[62]

Limitations of surveillance data

All of the data presented here have important limitations. In general, disease surveillance systems have sensitivity that is less than 100%, so under-count cases. This is particularly the situation with systems that require an active reporting process, such testing and reporting of positive RAT results by members of the public. Systems based on well-recorded events, such as hospitalisations and deaths, are likely to be far more sensitive to COVID-19 but still have limitations because of requirements for clinical judgement, testing and accurate recording. Active surveillance based on wastewater testing is also likely to provide consistent measurement of the presence of COVID-19 infections in a community.

Similarly, it is difficult to estimate the future course of the pandemic as it transitions to being an endemic infection. As noted (under *Future course of the pandemic*), there are multiple contributing factors to these future epidemiological scenarios. The limitations of current surveillance data add further uncertainties.

International assessments depend on countries having at least a moderate degree of comparability of data collection and reporting. Measures like excess mortality may be more valid in some situations than routine reporting of specific outcomes, such as COVID-19 mortality. However, excess mortality is also an imperfect measure because it is sensitive to the estimated baseline, which is becoming increasingly difficult to reliably extrapolate from pre-pandemic trends, and it cannot distinguish between deaths that are directly related, indirectly related and unrelated to the pandemic. Composite indexes, such as the Oxford Stringency Index, inevitably involve simplification of the policy responses in different countries (particularly for countries with very heterogeneous response across jurisdictions such as the US) to provide a single measure that can be used for comparison purposes.

Appendix 2: Timing of transitions through different COVID-19 response strategies

Here we summarise when New Zealand transitioned through different pandemic response strategies, from elimination to mitigation. We provide a rationale for assigning a date for each transition based on when the strategy was implemented.

It is important to note the limitations of this process. Government officials did not necessarily use standard terms for describing disease control strategies, so we have to infer them from the description of the measures being used and their aims. Suppression and mitigation strategies are on a spectrum rather than having a precise definition. Also, the implementation of specific strategies often included multiple incremental steps. For these reasons, the transition dates are indicative rather than being precise.

Elimination strategy

The elimination strategy aims to reduce transmission of an infectious disease to zero for a defined geographic area and time period.[28,87]

The elimination strategy was effectively announced on 23 March 2020, with New Zealand placed on Alert Level 3 immediately and a proposal to move to Alert Level 4 at 11:59 pm on 25 March. Government leaders and officials did not use the term elimination until several weeks later, but there was a strong implication that the intent was to eliminate COVID-19 from New Zealand.

We have therefore set the start day of the elimination strategy as **26 March 2020.**

The strategy achieved its aim of eliminating COVID-19 infection with the last case identified in early May and a move to Alert Level 1 on 8 June 2020, effectively declaring the end of person-to-person transmission within New Zealand.[127] Elimination continued successfully across New Zealand, with occasional small outbreaks, until the Delta variant outbreak was detected in Auckland on 17 August 2021, with New Zealand being placed back on Alert Level 4. This outbreak proved difficult to eliminate in Auckland, necessitating a change in strategy.

Suppression strategy

The suppression strategy aims to reduce the transmission of an infectious disease and the consequences of infection to minimise its health burden.[26,87]

The transition from elimination to suppression was signalled on 4 October 2021 when the Government announced that the elimination strategy would be phased out.[128] It would be replaced with the COVID-19 Protection Framework or "traffic lights" system.[129] Implementation happened at 11:59 pm on 2 December 2021, when the Alert Level System was retired and the COVID-19 Protection Framework was introduced.[129]

We have therefore set the start day for the suppression strategy as **3 December 2021**.

The strategy achieved its aim of suppressing the Delta variant wave of infection in both size and geographic spread.[30]

Mitigation strategy

The mitigation strategy provides a lower level of disease reduction than suppression, with a particular aim of protecting the health system from being overwhelmed.[87]

The transition from suppression to mitigation was signalled on 26 January 2022 with the Government announcing its three-phase public health response to Omicron.[130] The first phase articulated a suppression approach: "*Phase One is where we are now, and we are doing what we have successfully done with Delta—taking a 'stamp it out' approach … Our objective is to keep cases as low as possible for as long as possible to allow people to be boosted and children to be vaccinated without Omicron being widespread*." This phase retained PCR testing and a 14-day isolation period for cases. Phases Two and Three signalled a shift away from identifying all cases and attempting to interrupt transmission. Implementation of this shift in strategy occurred with the move to Phase Two of the Omicron response at 11:59 pm on 16 February 2022.

We have therefore set the start day for the mitigation strategy as **17 February 2022.** Other measures associated with elimination and suppression were removed after this date, notably a phased reduction in border controls.[131]

This change to mitigation was also a pragmatic response to the introduction and rapid spread of Omicron cases. The first case of community transmission of Omicron in New Zealand was reported on 18 January 2022. Cases accelerated from 28 January and steeply during February, with a peak of almost 24,000 reported cases on 8 March. Arguably, the mitigation strategy achieved its aim, as the New Zealand healthcare system was stressed but not overwhelmed.