Supporting Information

Further details on methodology of model 1

Rationale for R_{NPI}: Estimates of the reproductive number for COVID-19 in the absence of social distancing restrictions range from 2 to 4 for non-VOC SARS-CoV-2 [41]. Currently identified variants have higher transmission rate than previously-predominant strains, which acts to increase R_{NPI}. It has also been reported to show some potential for immune escape [13]. However, we model the maintenance of symptomatic testing and contact tracing, which can reduce R_{NPI} by $1/3$ if done rapidly, optimally, and with the capacity to scale up as cases rise [42]. We therefore explore relaxation from $R_{\text{NPI}} = 2.2$ to $R_{\text{NPI}} = 2.5$, both in the rapid and gradual reopening scenarios. In supplementary analyses, we explore relaxation to a wider range of R_{NPI} values, ranging from 2.4 to 5. Note that in British Columbia, early estimates of R_0 for the original COVID-19 virus were approximately 3 [43]; with the Alpha and Delta variants both estimated to increase the transmissibility by approximately 100%, this would place Delta (in BC pre-Omicron) at an R_0 of over 6 [44, 45]. However, a range of measures are in place at the time this analysis was done pre-Omicron wave, including testing, indoor mask use and vaccine mandates, workplace screening and other measures, motivating a lower R_{NPI}.

Vaccine efficacy: In our model vaccine efficacy consists of two components: v_e, efficacy against infection (what fraction of infections are prevented) and v_p, efficacy against symptoms when infection does occur (what fraction of cases infected after vaccination do not have symptoms, including severe outcomes). To have a symptomatic case after vaccination, the vaccine has to both fail to prevent disease and symptoms, so efficacy against symptomatic infection is $v_d = 1 - (1 - v_e)(1 - v_p)$. We take our baseline values from studies on the Pfizer vaccine, giving $v_d = 95\%$ protective against symptomatic infection [46] and $v_e = 80\%$ protective against infection [47], implying a value of $v_p = 75\%$.

If the vaccine fails to protect against infection in an individual, but does prevent symptoms, in our model the individual is assumed to contract the virus and transmit to others

at the same rate as an unvaccinated individual. It is likely that those who are vaccinated but infected anyway are less infectious due to lower viral loads than those who are infected without vaccination, and it is likely that they would not have symptoms. In a framework where testing is driven by symptoms and those with symptoms are encouraged to isolate, asymptomatic individuals will not know they are ill and will likely remain circulating and infectious for longer than those who develop symptoms. Thus, longer duration of infectiousness (vaccinated-but-infected individuals may transmit more because they do not have symptoms and therefore do not isolate), and lower per-unit-time transmission (due to a reduced viral load) act in opposing directions. In our model we assume that these effects balance out.

Vaccine acceptance: We model age-based vaccine uptake according to data from the vaccine rollout by age in BC [48]. This includes highest uptake in older age categories (98% in those 80+), and lowest uptake in younger age categories (30% in those 12-19). Vaccine hesitancy is modelled as around 10% lower in essential worker categories. A full description of the model age-based vaccine uptake is included in Supplementary Table S2.

Vaccine rollout: Following BC vaccine rollout strategy [48], we vaccinate those 80+ and in long term care (LTC) settings (not modelled explicitly, but hospitalization rates are adjusted to reflect protection in LTC [5]) first, followed by younger age groups 12+. To match the observed age-based trajectory [48] (whilst taking into account that we do not model the two-dose vaccine regimen), we model a rapid uptake in vaccines during May-June 2021 in which 2% of each age group are vaccinated per day up to uptake levels observed during that time (see Supplementary Table S2). This is followed by a slower period of 0.2% per day in July-Aug and then 0.22% per day from September onwards, until the overall uptake levels described in in Supplementary Table S2 are reached. Vaccination of those aged 12-19 does not begin until July 3rd 2021. The full age-based rollout is shown in Supplementary Figure S9.

Hospitalization and death rate: Hospitalization and death rate estimation can be found in [5], where the authors estimated rates using data from Public Health Agency of Canada

(PHAC). We also estimated hospitalization and death rate for vaccinated individuals based on v_p. If an individual is not vaccinated, we calculate the number of hospitalization and death based on [5]. If an individual is fully vaccinated, we calculate the rates by multiplying $1 - v_p$ to non-vaccinated case, where $1 - v_p$ is the probability of vaccine failure to protect against infection.

Results from model 1

Using the age and contact structured model, we explore the severity and risk breakdown of gradually reopening over a 300 day period compared with a near-instantaneous reopening. In this pre-Omicron analysis, we find that under our baseline vaccine efficacy assumptions, even after most of the rollout is complete, we will not be in a position to reopen without seeing a rise in cases. This is consistent with the fact that the decline in cases before the Omicron wave (approximately 2% per day) was slow, leaving little leeway for increasing transmission without moving from a decline to a rise. From the date of reopening (Dec 2021) onwards, near-instantaneous reopening leads to 500K cumulative reported cases and 19K hospitalizations over 900 days while gradual reopening leads to 450K cumulative cases and 17K hospitalizations, in the BC population of 5 million people. These results and further scenarios are presented in the Supplement (Figures S1, S3, S4 and S5), where we consider gradual vs rapid reopening from $R_{\text{NPI}} = 2.2$ to $R_{\text{NPI}} = 2.4, 2.6$ and 3.0, respectively. In all scenarios considered, there are fewer cumulative cases and hospitalizations under gradual reopening than under rapid reopening.

We consider reopening at two levels of vaccination coverage - BC's 90% coverage and a counterfactual 70% scenario. Figure S2 shows the simulated outcome if we relax measures to $R_{\text{NPI}} = 2.5$ for the two scenarios, according to the age and contact based rollout. Reopening "fully" to $R_{\text{NPI}} = 2.5$ at 70% vaccination coverage leads to considerable rises in infections and hospitalizations. In both cases hospitalizations do not exceed hospital capacity (just under 40 per 100K) [49], with estimated maximum hospitalizations at 20 and 9 per 100K, for 70% vaccination and 90% vaccination, respectively. However, reopen-

ing when 70% are vaccinated leads to far more hospitalizations (600K cumulatively) than when reopening after 90% of the population are vaccinated (450K cumulatively). These results and further scenarios are shown in Supplementary Figures S2, S6, S7 and S8, where we consider reopening to $R_{\text{NPI}} = 3.0, 4.0$ and 5.0, respectively, and show the cumulative cases for each scenario. 90% vaccination coverage naturally leads to substantially fewer cases than 70% coverage. These analyses are consistent with what was observed during the Omicron wave before public health measures were re-introduced to control rapid spread of infection.

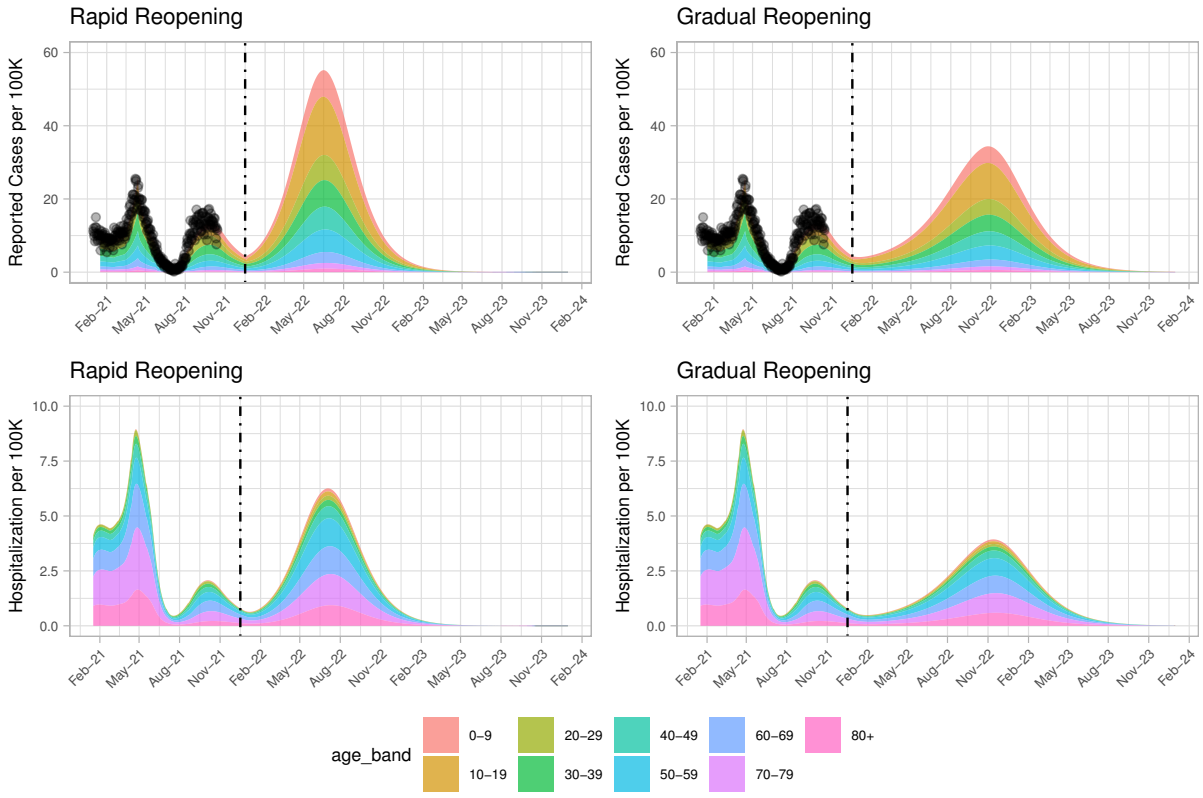

Figure S1: Comparison of the impact of gradual vs rapid reopening, from $R_{\text{NPI}} = 2.2$ to $R_{\text{NPI}} = 2.5$, on case and hospitalization rates. Gradual reopening is modelled as occurring linearly over a 300 day window. We assume 90% vaccination coverage of those aged 12+ before reopening , consistent with BC at the time of writing. Dashed lines represent reopening time. No further vaccines are deployed after reopening in both scenarios.

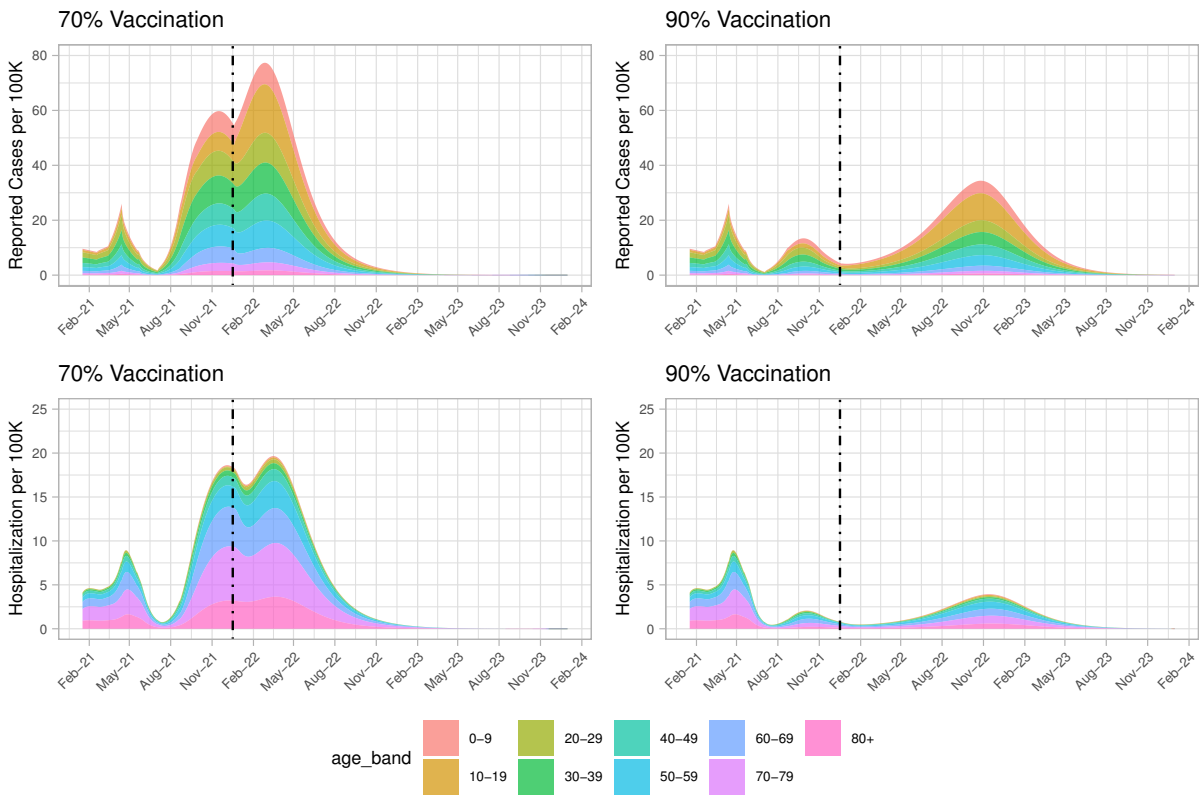

Figure S2: **Reopen gradually at 70% or 90% vaccination coverage**. Left frame showing reported cases per 100K of the population for the 70% vaccination coverage scenarios. The right panel reported cases per 100K of the population for the 90% vaccination coverage scenarios. Assuming reopening to $R_{\text{NPI}} = 2.5$.

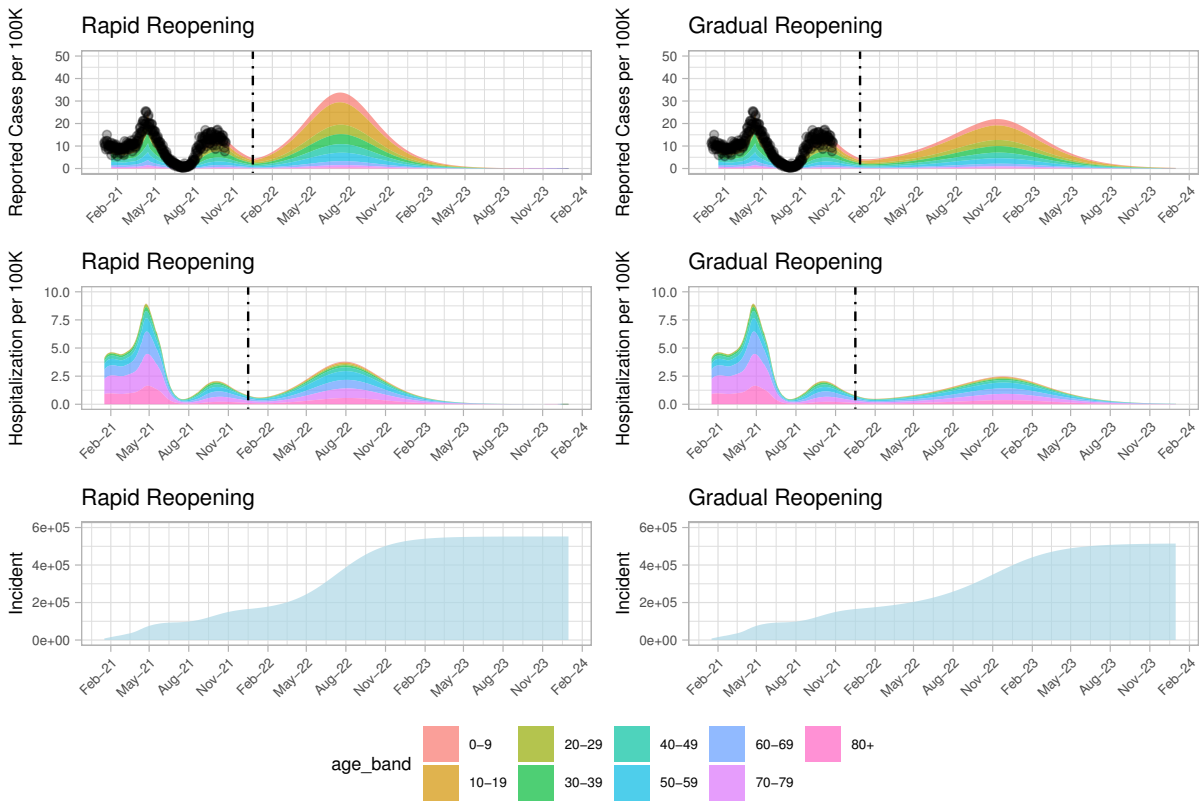

Figure S3: Comparison of the impact of gradual vs rapid reopening, from $R_{\text{NPI}} = 2.2$ to $R_{\text{NPI}} = 2.4$, on case and hospitalization rates. Gradual reopening is modelled as occurring over a 300 day window. Dashed lines represent reopening time. No further vaccines are deployed after reopening in both scenarios. The number of cases is 385K and 284K, for rapid and gradual scenarios, respectively, after reopening. The difference between scenarios equal 101K.The number of hospitalizations is 15K and 13K, for rapid and gradual scenarios, respectively, after reopening. The difference between scenarios equal 2K.

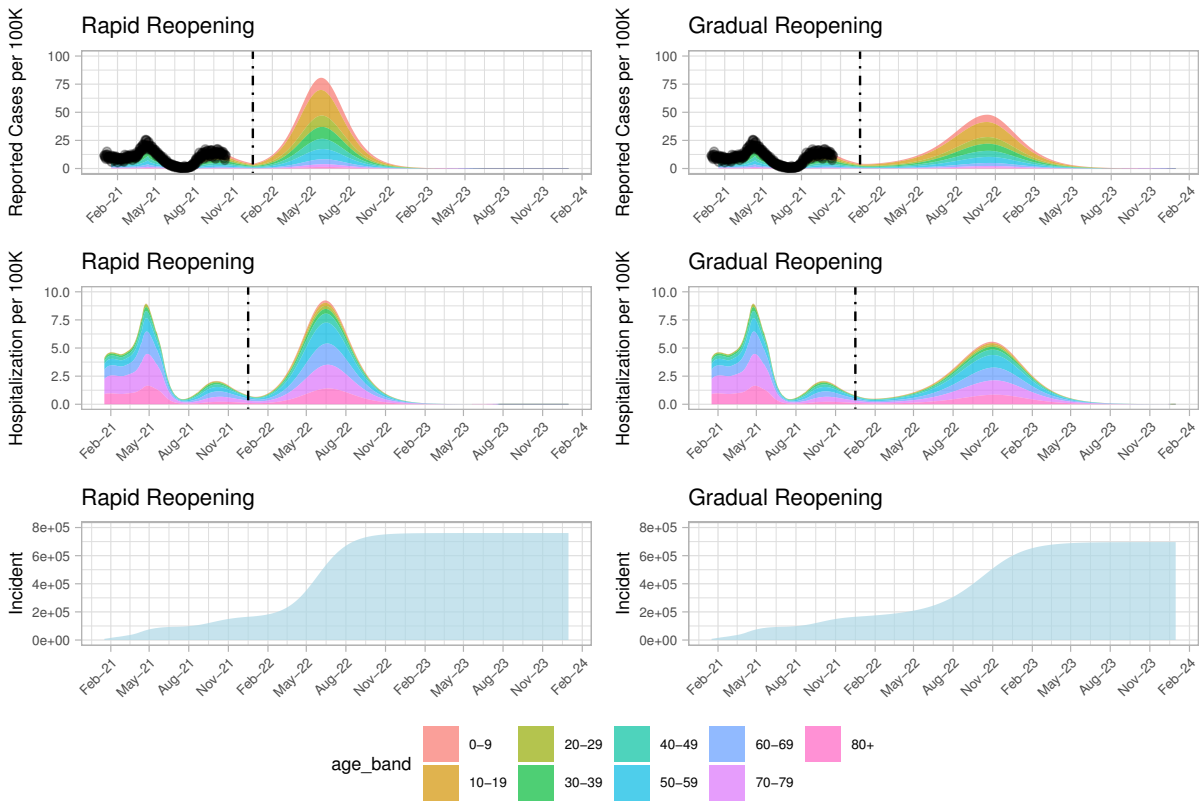

Figure S4: Comparison of the impact of gradual vs rapid reopening, from $R_{\text{NPI}} = 2.2$ to $R_{\text{NPI}} = 2.6$, on case and hospitalization rates. Gradual reopening is modelled as occurring over a 300 day window. Dashed lines represent reopening time. No further vaccines are deployed after reopening in both scenarios. The number of cases is 593K and 414K, for rapid and gradual scenarios, respectively, after reopening. The difference between scenarios equal 179K.The number of hospitalizations is 23K and 20K, for rapid and gradual scenarios, respectively, after reopening. The difference between scenarios equal 3K.

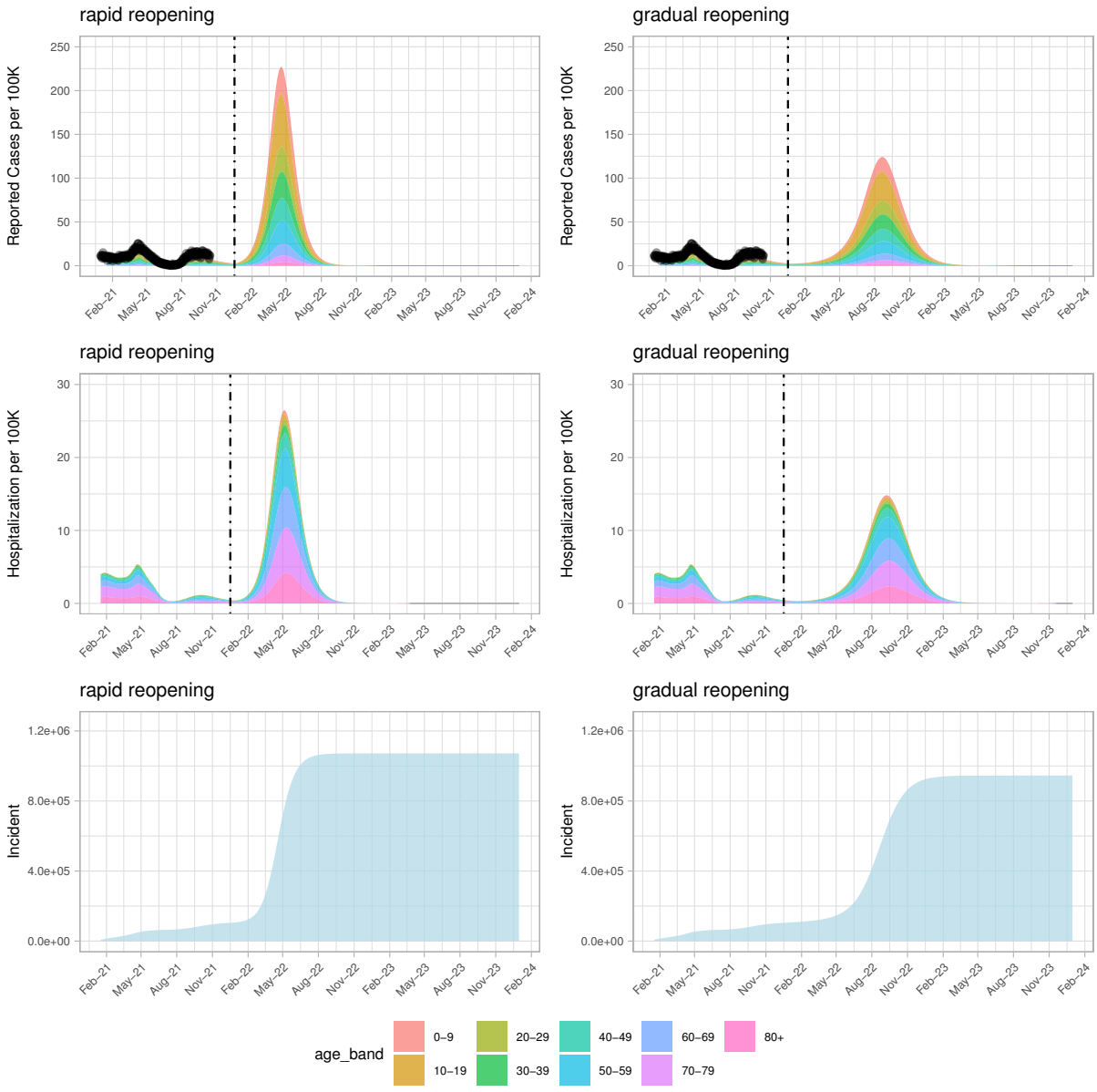

Figure S5: Comparison of the impact of gradual vs rapid reopening, from $R_{\text{NPI}} = 2.2$ to $R_{\text{NPI}} = 3.0$, on case and hospitalization rates. Gradual reopening is modelled as occurring over a 300 day window. Dashed lines represent reopening time. No further vaccines are deployed after reopening in both scenarios. The number of cases is 930K and 597K, for rapid and gradual scenarios, respectively, after reopening. The difference between scenarios equal 333K.The number of hospitalizations is 39K and 32K, for rapid and gradual scenarios, respectively, after reopening. The difference between scenarios equal 7K.

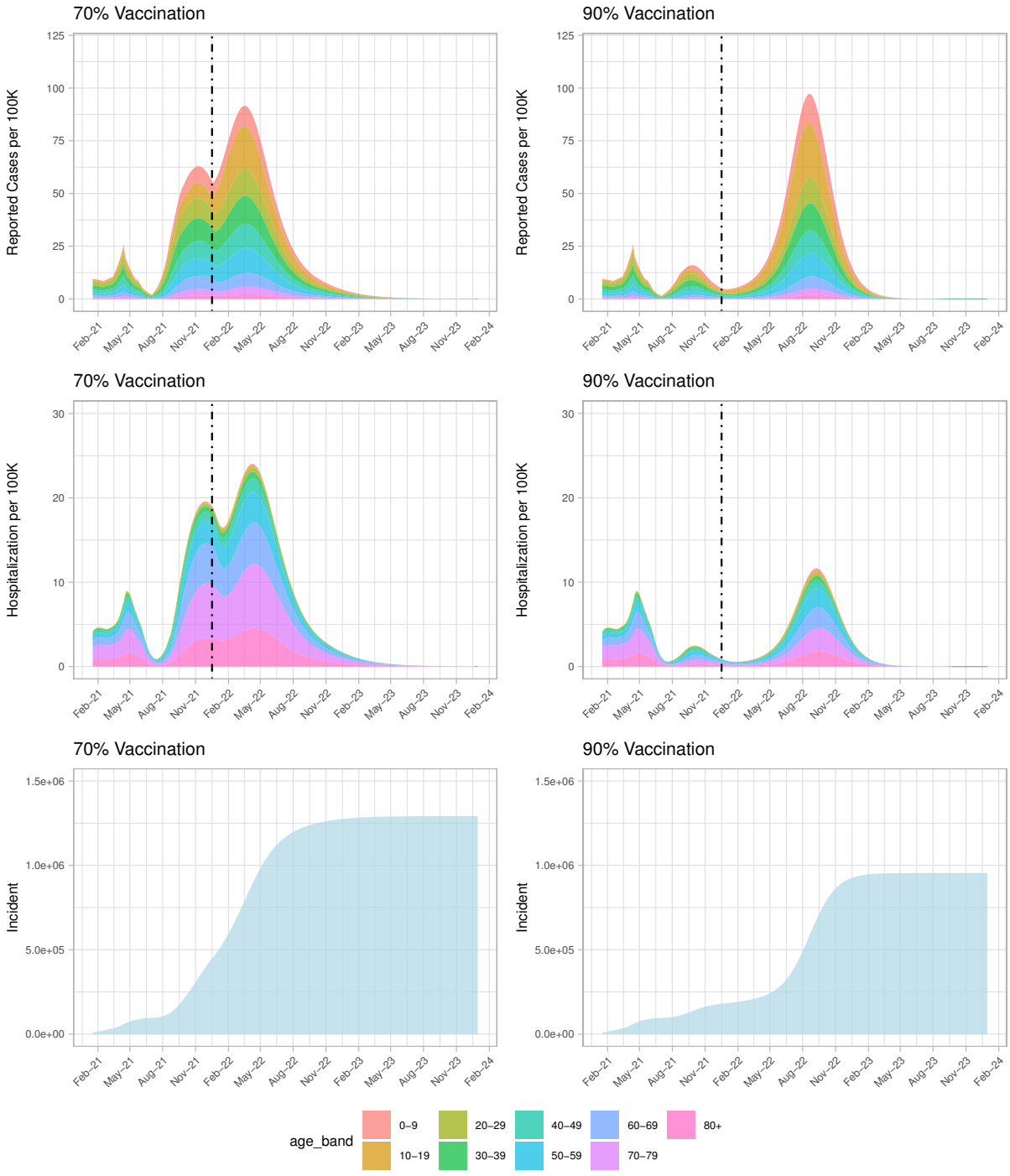

Figure S6: **Reopen gradually at 70% or 90% vaccination coverage**. Top panel showing reported cases per 100K of the population for the two vaccination coverage scenarios. Middle panel showing hospitalization per 100K of the population. Bottom panel showing the cumulative cases for the two vaccination coverage levels. Gradual reopening is modelled as occurring over a 300 day window. Dashed lines represent reopening time, from $R_{\text{NPI}} = 2.2$ to $R_{\text{NPI}} = 3.0$

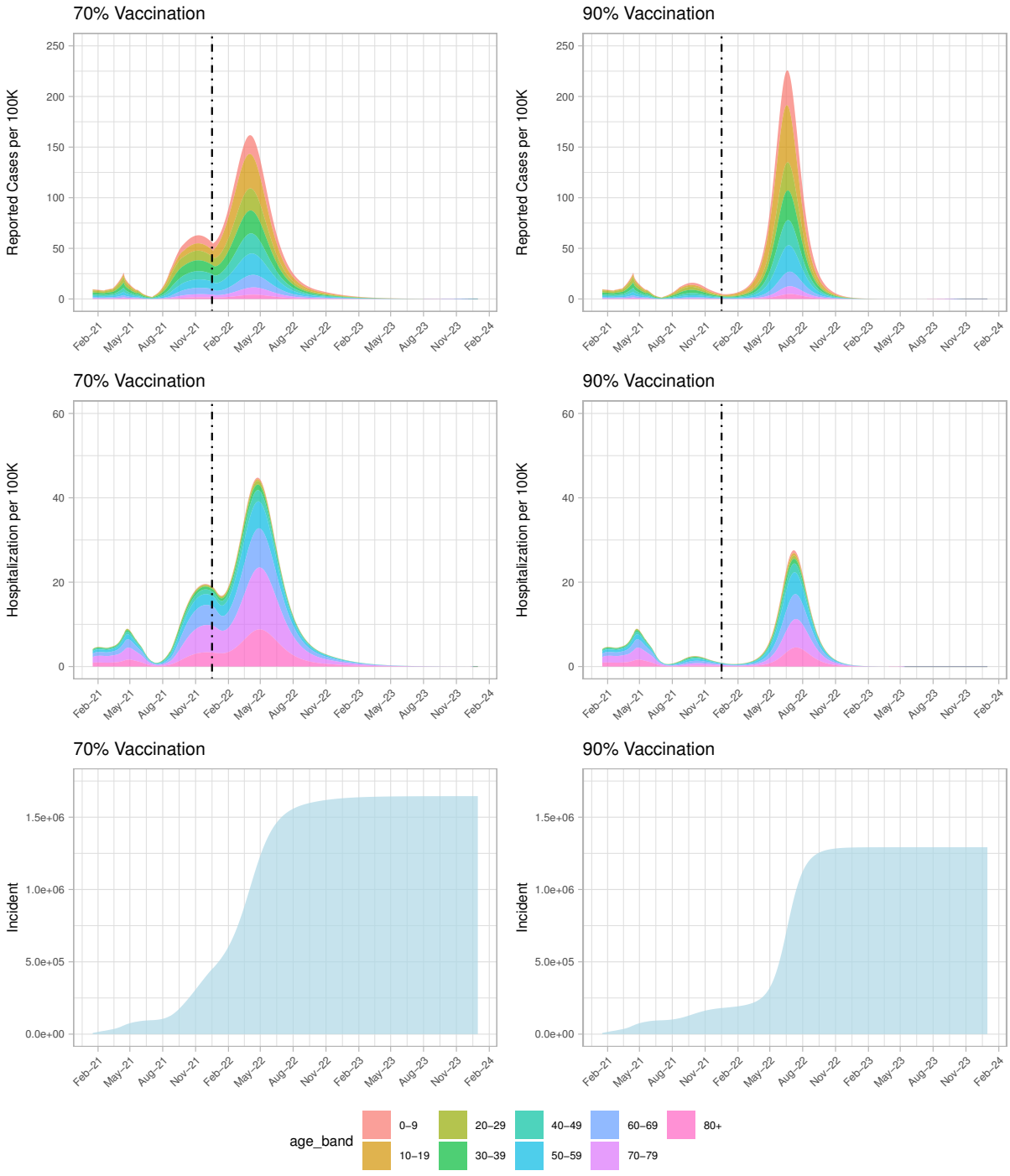

Figure S7: **Reopen gradually at 70% or 90% vaccination coverage**. Top frame showing reported cases per 100K of the population for the two vaccination coverage scenarios. Middle panel showing hospitalization per 100K of the population. Bottom panel showing the cumulative cases for the two vaccination coverage levels. Gradual reopening is modelled as occurring over a 300 day window. Dashed lines represent reopening time, from $R_{\text{NPI}} = 2.2$ to $R_{\text{NPI}} = 4.0$

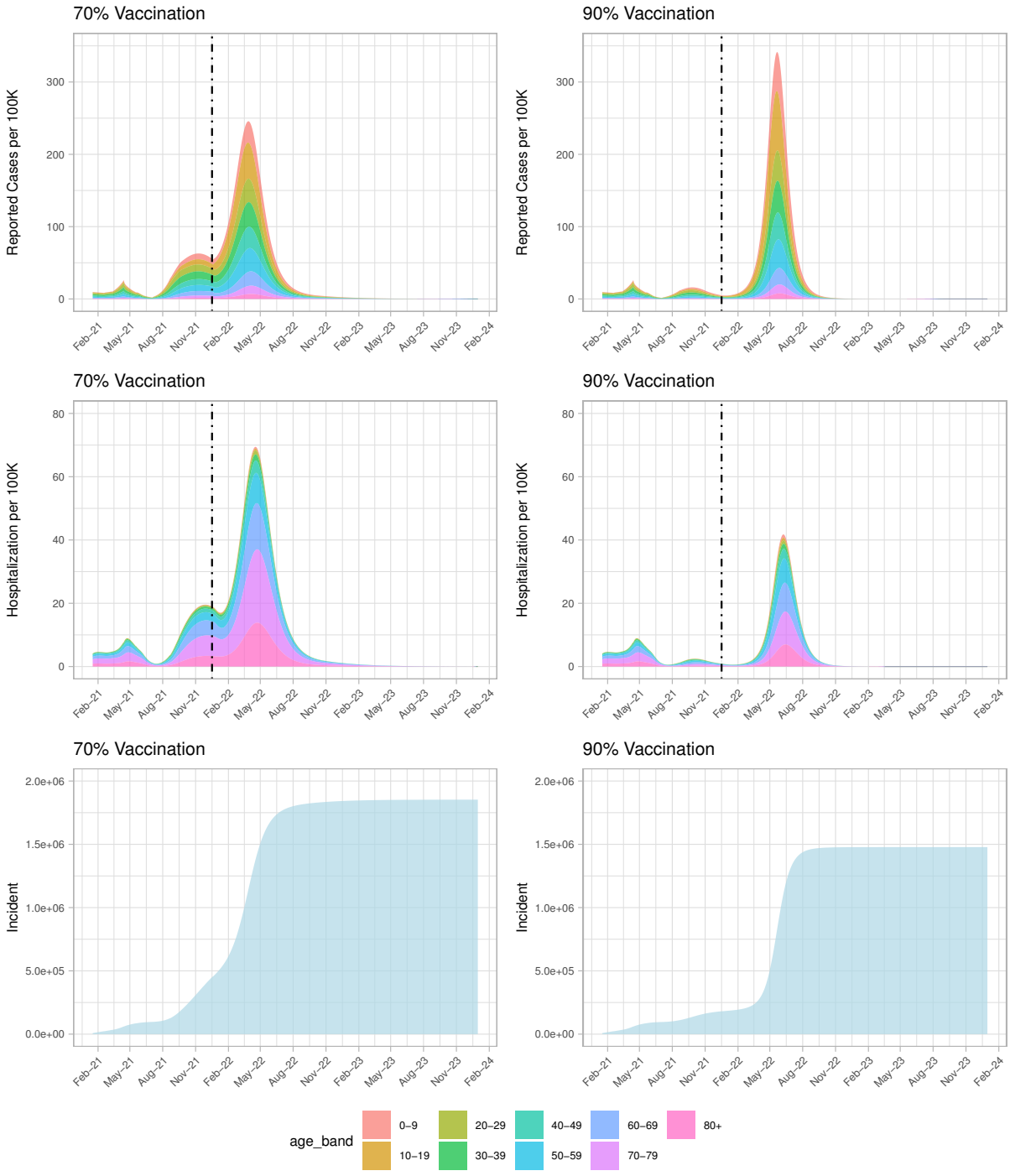

Figure S8: **Reopen gradually at 70% or 90% vaccination coverage**. Top frame showing reported cases per 100K of the population for the two vaccination coverage scenarios. Middle panel showing hospitalization per 100K of the population. Bottom panel showing the cumulative cases for the two vaccination coverage levels. Gradual reopening is modelled as occurring over a 300 day window. Dashed lines represent reopening time, from $R_{\text{NPI}} = 2.2$ to $R_{\text{NPI}} = 5.0$

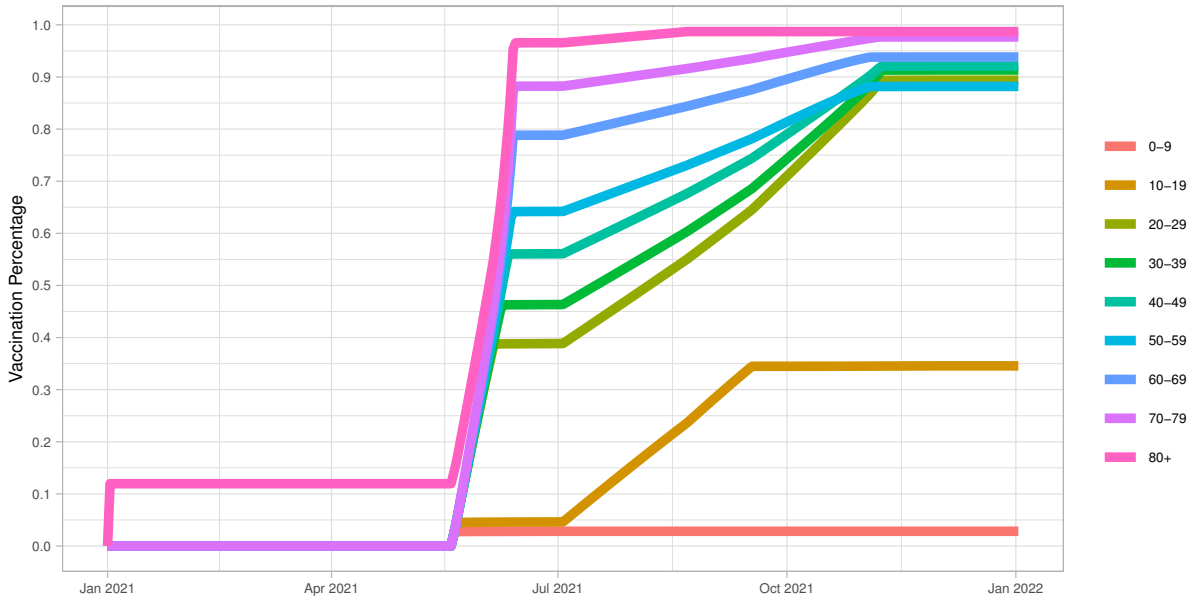

Figure S9: **Vaccine rollout in the age and contact structured model**. We assume 12% of the 80+ age group are fully vaccinated on January 01, 2021. Vaccination by age for those aged 20+ starts on May 22, 2021 and for those aged 10-19 starts on July 3,2021. This figure includes essential workers.

Important Dates Specification

Important Date	Description
2021-01-01	Simulation starts
2021-02-15	The number of cases gradually decreased to 400
2021-03-21	The number of cases gradually increased to 575
2021-04-15	The number of cases rapidly increased to 1250
2021-07-22	The number of cases rapidly decreased to 45
2021-09-01	The number of cases gradually increased to 500

Table S1: Important dates were identified from British Columbia COVID-19 reports that illustrate rapid changes in daily cases. These important dates are determined in the table.

Age group	Vaccination start date	May-June uptake	Overall uptake
0-9	No vaccination	0%	0%
10-19	2021-07-03	0%	35% of those aged 12-19
20-29	2021-05-22	40%	89%
30-39	2021-05-22	45%	90%
40-49	2021-05-22	55%	92%
50-59	2021-05-22	65%	88%
60-69	2021-05-22	80%	95%
70-79	2021-05-22	88%	97%
80+	2021-01-01	95%	98%

Table S2: **Specifics of the age-based vaccine rollout in the age and contact structured model.**

We compare herd immunity threshold calculated from the age and contact structured model and a simple SIR model, and we find good agreement (Figure 2). Also in model 2, we explore scenarios where booster doses are not given after 70% of the population are immune to infection due to vaccination (Figure S10), and the endemic state as function of various parameters with pessimistic baseline assumptions: $\nu = 0.5\%$ per day, $R_{NPI} = 5$ and $v_e = 80\%$ (Figure S11). Further explorations are done with model 2, covering wider range of R_{NPI} and vaccination coverage levels and vaccination rollout strategies (Figures S3-S9).

Further analysis and scenarios from Model 2

The prevalence at endemic equilibrium is obtained analytically by solving equation (1) at equilibrium.

$$I^* = \frac{A - \mu^3 + B\mu^2 + C\mu + D}{2(\mu^2 + (w+\gamma+\sigma)\mu + (w+\gamma)\sigma + \gamma w)/(R_{\mathrm{NPI}}\gamma)} \tag{S1}$$

where:

$$A = \sqrt{E(\nu v_e)^2 + G(\nu v_e) + 4H(\mu + w)}$$
$$B = (-w - (\nu v_e) - \gamma - \sigma)$$
$$C = (-w - (\nu v_e) + (R_{\text{NPI}}\gamma) - \gamma)\sigma + (-w - (\nu v_e))\gamma)$$
$$D = ((-w - (\nu v_e))\gamma + w(R_{\text{NPI}}\gamma))\sigma)$$
$$E = (\mu + \sigma)^2(\mu + \gamma)^2$$
$$F = (f - 1/2\mu - 1/2\sigma)$$
$$G = (Jw + 4(\mu + \sigma)(\sigma(-1/2\mu + f)(R_{\text{NPI}}\gamma) + 1/2\mu(\mu + \sigma)(\mu + \gamma))(\mu + \gamma))$$
$$H = (Iw + 1/4(R_{\text{NPI}}\gamma)^2\mu\sigma^2 + (\mu + \sigma)(-1/2\mu + f)(\mu + \gamma)\sigma(R_{\text{NPI}}\gamma) + 1/4\mu E)$$
$$I = (1/4(R_{\text{NPI}}\gamma)^2\sigma^2 + (F\gamma + (\mu + \sigma)(-1/2\mu + f))\sigma(R_{\text{NPI}}\gamma) + 1/4E)$$
$$J = (4(F\gamma + (\mu + \sigma)(-1/2\mu + f))\sigma(R_{\text{NPI}}\gamma) + 2E)$$

Equation (1) has no disease free equilibrium when $f > 0$, since cases are continuously introduced into the population. When $f = 0$, the disease free and endemic equilibrium points exist and their stability depends on R_{NPI}. The basic reproduction number in the absence of vaccination is $R_0 = \frac{\beta\sigma}{(\mu+\gamma)(\mu+\sigma)}$, with vaccination and waning $R_e = \frac{\beta\sigma(\mu+w)}{(\mu+\gamma)(\mu+\sigma)(\mu+\nu v_e+w)}$

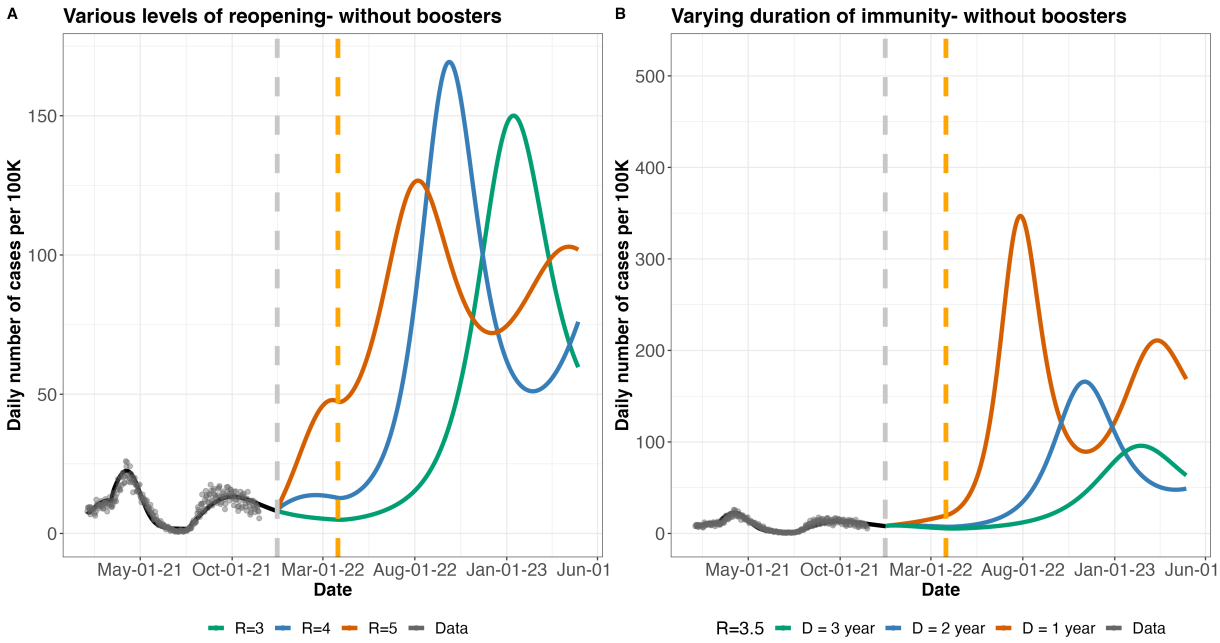

Figure S10: **Near-future model projections and various possible paths to COVID-19 endemicity in BC without boosters** A. Projected daily cases for different levels of reopening: assuming the province reopen further at the end of November 2021. R_{NPI} indicates how much reopening is done. Importation rate f is fixed at 2 cases per 100K per day, vaccine efficacy v_e at 80%, and duration of immunity D is set to 2 years. B. Projected case numbers as a function of various lengths of duration of immunity (1 -3 years). While R_{NPI} is set to 3.5, f is 2 cases per 100K per day, v_e is 80%. The orange vertical dashed line indicate the point where vaccine boosters are suspended with 70% of the population completely immune to infection

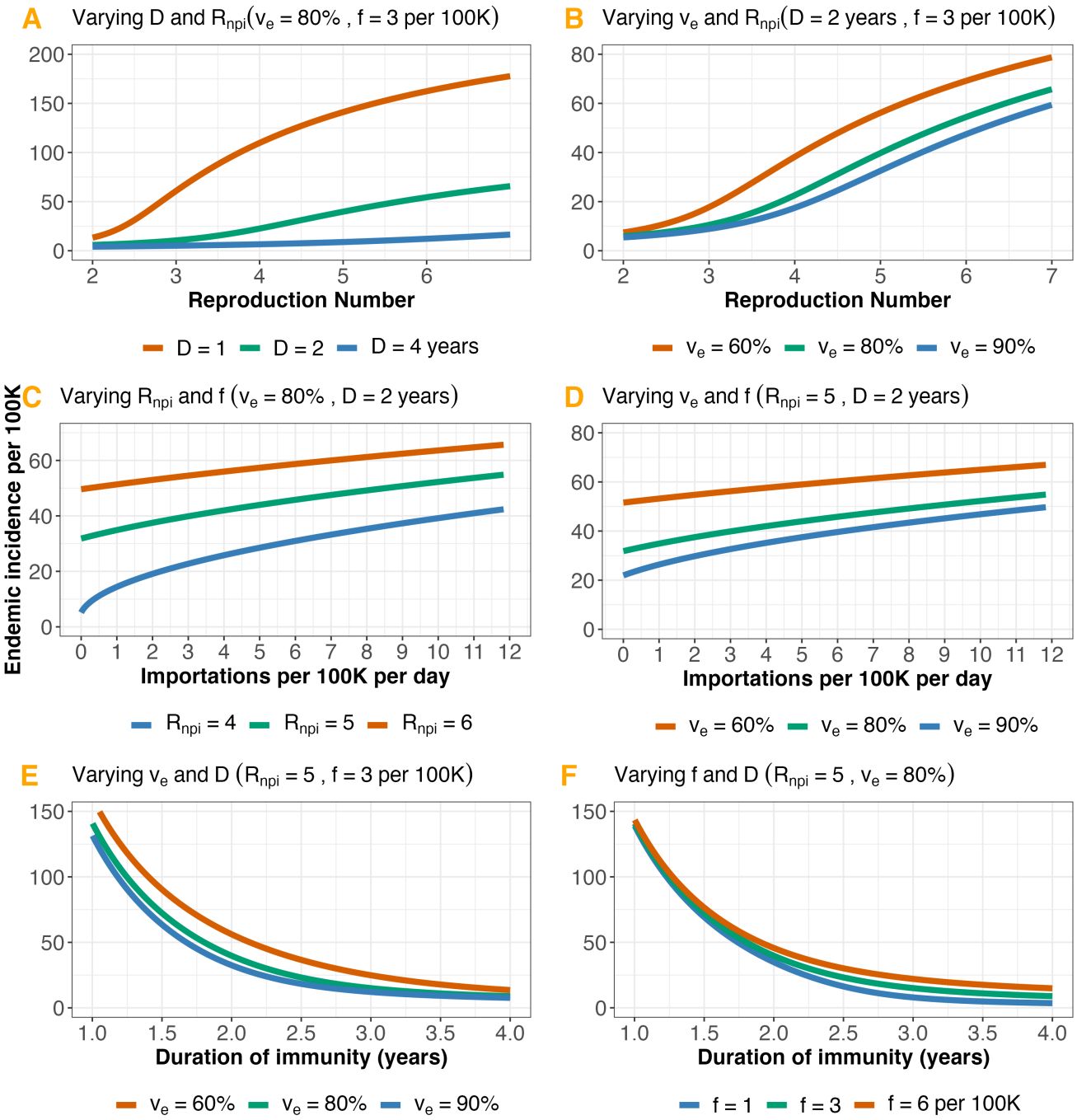

Figure S11: **Endemic incidence as a function of:** A. The reproduction number (R_{NPI}) and duration of immunity (D). B. R_{NPI} and vaccine efficacy (v_e). C. Importation rate (f) and R_{NPI}. D. f and v_e. E. D and v_e. F. D and f. Baseline parameter values are: $f = 3$ cases per 100K per day, vaccination rate $\nu = 0.5\%$ per day, $D = 2$ years, $v_e = 80\%$, and $R_{\text{NPI}} = 5$. In each subplot three parameters are varied at the same time: the two parameters declared in the subplot title and the parameter presented in the horizontal axis of the subplot, while the remaining two parameters are fixed with their values declared in the subplot title