Appendix (as supplied by the authors)

An agent-based model of SARS-CoV-2 transmission in Canada: forecasting impacts of non-pharmaceutical public health interventions

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Agent-based model technical background

We developed an age-stratified agent-based simulation model for the transmission of SARS-CoV-2 in Canada. We assumed community transmission began on February 7, 2020 based on the date of onset reported by the first domestic COVID-19 cases emerging in Canada (1). We initialized an outbreak with six symptomatic cases over a 2-week period to propagate local transmission. Agents were modelled in ten distinct age groups to account for differences in age-specific health outcomes and contact rates (Table S1). The model was simulated using a daily time step over 700 days (day 0 representing February 7, 2020 to day 700 representing January 20, 2022).

Population structure and demographics

The model is a simplified version of movement and connectivity in the Canadian population. Models were run on a population size of 100,000; with household structure and demographics scaled to the Canadian population (Tables S1 and S2) (2, 3).

Table S1. Proportion of agents by age group

Category	Age group	Proportion of agents distributed according to the 2019 Canadian population estimates (2)
Child1	0 to 4	0.051695
Child2	5 to 9	0.054254
Child3	10 to 14	0.054052
Youth	15 to 19	0.056256
Adult1	20 to 44	0.338052
Adult2	45 to 54	0.130332
Adult3	55 to 64	0.13997
Senior1	65 to 74	0.101182
Senior2	75 to 84	0.051903
Elderly	>=85	0.022301

Table S2. Household structure in the model

Household size	Number of households according to the 2016 Canadian census (3)	Total agents
1-member household	11,725	11,725
2-member household	13,900	27,800
3-member household	6,200	18,600
4-member household	5,800	23,200
5-member household	2,500	12,500
6-member household	750	4,500
7-member household	125	875
8-member household	100	800
Total	41,100 households	100,000 agents

Model environment and agent movement

Agents were assigned to a designated household and common environment (school, workplace or a mixed age meeting venue) according to their age using the Prem *et al* (2017) projections for Canada as a guide to assigning agents of age groups that are likely to come into contact with each other at home, at work, at school and in other locations; we call these other locations mixed age venues (4). Mixed age venues are defined as any place where individuals have contact with agents from a range of different age groups, this could include restaurants, cafes, shopping centres, museums, libraries, movie theatres, grocery supermarkets, public parks, and beaches. In our model, there is no distinction between indoor and outdoor environments. In comparison, workplaces are defined by a more restrictive group of age groups mixing, primarily those between the ages of 16 and 65 with most agents assigned from the middle year age groups. Agents under 17 years and over 65 years were restricted from being assigned to workplaces. Schools represent daycares, elementary and high schools with most agents between the ages of 0 to 16 assigned to schools. Agents were distributed into the three common environments on weekdays as summarised in Table S3. A total of 40 schools, 750 workplaces and 415 mixed age venues per 100,000 persons were modelled to give an approximate density of 500 agents/school, 50 agents/workplace and 100 agents/mixed age venue. These were our estimates for the average Canadian population.

Table S3. Distribution of agents by age into common mixing environments on weekdays.

Category	Age group	Schools	Workplaces	Mixed age venues
Child1	0 to 4	60%	0%	40%
Child2	5 to 9	100%	0%	0%
Child3	10 to 14	100%	0%	0%
Youth	15 to 19	80%	10%[1]	10%
Adult1	20 to 44	2%	50%	48%
Adult2	45 to 54	5%	60%	35%
Adult3	55 to 64	5%	70%	25%
Senior1	65 to 74	0%	30%	70%
Senior2	75 to 84	0%	0%	100%
Elderly	>=85	0%	0%	100%

At model initialization, agents move between their household and common environment during the weekday spending on average of eight hours per day outside of home. Each weekend, a different group of agents are selected at random to visit a new mixed age environment than their regularly assigned one; and we assumed schools and workplaces are closed on weekends.

Mobility varied by age and between weekdays and weekends; we assumed older agents were not as mobile during the weekdays as younger individuals but for simplicity we assumed weekend movement was uniform across age groups (Table S4). Mobility was determined daily for each agent; agents could leave the household if selected by chance based on the probability estimated for their age group.

[1] Only agents 17 years or older could be assigned to workplaces

Table S4. Mobility probabilities by age group on weekdays and the weekend.

Category	Age group	Mobility on weekdays	Mobility on the weekend
Child1	0 to 4	0.7	0.7
Child2	5 to 9	0.95	0.7
Child3	10 to 14	0.95	0.7
Youth	15 to 19	0.95	0.7
Adult1	20 to 44	0.9	0.7
Adult2	45 to 54	0.9	0.7
Adult3	55 to 64	0.9	0.7
Senior1	65 to 74	0.8	0.7
Senior2	75 to 84	0.7	0.7
Elderly	>=85	0.6	0.7

Health and hospitalization states of agents

We developed a framework of compartments representing epidemiological health states of agents (Figure S1). All agents begin as susceptible (we assume the Canadian population is completely naïve to SARS-CoV-2) except for infected agents used to seed transmission. Infection occurs on successful contact between susceptible and infectious agents. Infectious agents occur as four states: asymptomatic, pre-symptomatic, mild symptomatic and severe symptomatic. We assumed severe cases, after a pre-symptomatic period (Table S5), will remain at home until hospitalization and can only transmit infection to household members at a reduced rate of 50%. In contrast, asymptomatic, pre-symptomatic and mild cases can infect both at home and in common environments. On infection, agents progress through different health states beginning with the exposed states (distinguished by those exposed by a symptomatic case and those exposed by an asymptomatic case) until either recovery or death is reached. We assumed recovered individuals remain immune from re-infection for the duration of the model run. The duration in which agents remain in each epidemiological health state varied between agents and was determined by sampling from probability distributions defined by the literature or Canadian data (Table S5).

Transmission of COVID-19 from infected agents to susceptible agents occur within the household and within common environments. For simplicity, the current model does not incorporate transmission during agent's commute or in other unique environments such as in hospitals or long-term care facilities. The model therefore represents the baseline number of infections, hospitalizations and deaths excluding isolated outbreaks such as those seen in long-term care facility, hospitals, and other localised outbreaks. To adjust for hospitalization and mortality rates that have been inflated due to deaths in long-term case facilities and hospitals, we removed cases linked to outbreaks in institutions and transmission in hospitals to provide a better estimate of hospitalization and mortality rate due to general community transmission (Table S5).

Figure S1. Schematic of the agent-based model structure for SARS-CoV-2 transmission

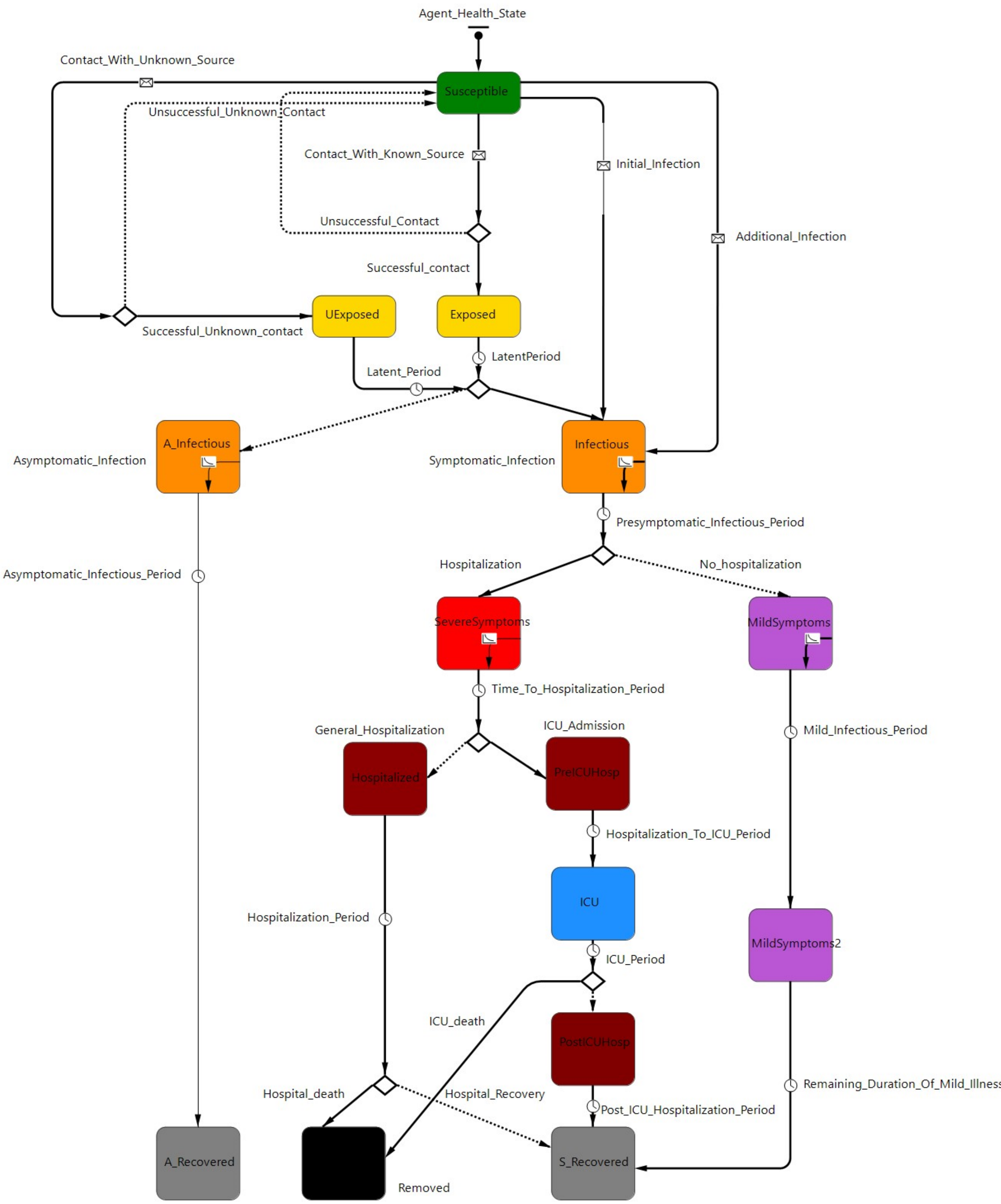


Table S5. Model parameters

Parameter (unit)	Description	Value(s)	Reference/s or sources of information
Transmission probability (β) (per contact)	β was calibrated to the model using Canadian case data linked to community transmission from February 20 to March 30, 2020 (see page 12 of supplementary material)	0.03931058 Due to a lack of data in the literature to date, we assumed β was uniform across age groups. This will need to be reassessed as new information about SARS-CoV-2 in children becomes available	Fitted value (5)
Age-specific contact rate (contacts per day)	Contact rate between individuals by age group. Younger agents have a higher contact rate than older agents.	9.0957 (0-4) 10.5341 (5-9) 13.0621 (10-14) 20.3667 (15-19) 15.3519 (20-44) 14.9039(45-54) 11.0106 (55-64) 6.5229 (65-74) 4.5929(75-84) 4.5929 (>=85)	(4)
Latent period (days)	Time from successful contact, i.e. infection, to the time when a person can transmit infection to another person	PERT distribution (2, 5, 3.77) μ (mean) – 3.68 σ (standard deviation) – 0.5	(6)
Probability of symptomatic infection (proportion)	There is mounting evidence to suggest that the asymptomatic infection rate varies by age. We used the following estimated proportions based on the cited literature. Adjusted for the Canadian population distribution, the values here represent an overall 35% asymptomatic rate	0.5 (0-4) 0.5 (5-9) 0.5 (10-14) 0.5 (15-19) 0.6 (20-44) 0.7 (45-54) 0.7 (55-64) 0.8 (65-74) 0.95 (75-84) 1.0 (>=85)	(7-12)
Pre-symptomatic infectious period (days)	Duration of time from when a case (who will eventually develop symptoms) can transmit infection to another person prior to becoming symptomatic	PERT distribution (1, 3, 2.5) μ – 2.33; σ – 0.33	(13-19)
Asymptomatic infectious period (days)	Duration of time from when a case (who will remain asymptomatic for the duration of	PERT distribution (3.5, 10, 6) μ – 6.25; σ – 1.08	(20)

	their illness) can transmit infection to another person		
Hospitalization (proportion)[2]	Proportion of symptomatic cases with severe and critical illness requiring hospitalization or ICU admission	0.03671 (0-4) 0.00818 (5-9) 0.01668 (10-14) 0.02658 (15-19) 0.05348 (20-44) 0.11904 (45-54) 0.21184 (55-64) 0.40341 (65-74) 0.52133 (75-84) 0.44169 (>=85)	(1)
Mild infectious period (days)	Duration of time in the first phase of mild illness when cases are symptomatic and can transmit infection to others	PERT distribution (3, 7, 3.5) μ – 4.0; σ – 0.67	(18, 21)
Remaining duration of mild illness (days)	Duration of time in the second phase of mild illness when cases are still symptomatic but are no longer able to transmit infection to others	PERT distribution (2, 5, 3) μ – 3.17; σ – 0.5	Estimate
Time to Hospitalization period (days)	Duration of time between when a case develops symptoms to when they seek medical care at the hospital	Normal distribution (0.5, 5) μ – 5; σ – 0.5	(22-25)
ICU admission (proportion)	Proportion of cases that are critical that are hospitalized first, and then move on to being admitted into the ICU	0.17241 (0-4) 0.0 (5-9) 0.29412 (10-14) 0.20513 (15-19) 0.22644 (20-44) 0.28866 (45-54) 0.30579 (55-64) 0.28292 (65-74) 0.15492 (75-84) 0.04819 (>=85)	(1)
Hospitalization period (days)	Duration of time a severe case spends in general hospitalization for medical care to the time that they recover or die. The lower range of 3 days is based on data reported by the provinces and territories as of June 6, 2020.	PERT distribution (3, 14, 10) μ – 9.5; σ – 1.83	(1, 25-31)

[2] COVID-19 cases linked to long-term care facilities and healthcare workers were removed to provide a better estimate of hospitalization rates and mortality rate of COVID-19 in the general population and because our model did not explore outbreaks from long-term care facilities and hospital transmission.

Hospitalization to ICU period (days)	Duration of time a critical case spends in hospital prior to being admitted into the ICU	Normal distribution (0.3, 3) μ – 3; σ – 0.3	(26-28, 32)
ICU period (days)	Duration of time a critical case spends in the ICU for medical care to post-ICU hospitalization or death	PERT distribution (4, 13, 8) μ – 8.17; σ – 1.5	(26-28, 30, 32-35)
Post-ICU hospitalization period (days)	Duration of time a critical case spends in hospital after being discharged from the ICU to recovery or to death	PERT distribution (3, 10 ,7) μ – 6.83; σ – 1.17	(26-28, 32)
General admission hospital beds and ICU beds	Number of beds available per 100,000 for COVID-19 patients	64 hospital beds per 100,000 5 ICU beds per 100,000	(36)
Mortality rate from general hospital admissions (proportion)	Age specific mortality rate occurring from general hospitalization. Approximately 40% of all deaths occurred from hospitalized cases. Mortality rate was doubled when hospital beds were overcapacity (37, 38)	0.0 (0-4) 0.0 (5-9) 0.0 (10-14) 0.0 (15-19) 0.0088 (20-44) 0.0188 (45-54) 0.0758 (55-64) 0.2252 (65-74) 0.352 (75-84) 0.4719 (>=85)	(1)
Mortality rate from ICU admissions (proportion)	Age specific mortality rate occurring from cases admitted into the ICU. Approximately 60% of all deaths occurred from ICU admitted cases. Mortality rate was doubled when hospital beds were at overcapacity (37, 38)	0.0 (0-4) 0.0 (5-9) 0.0 (10-14) 0.0 (15-19) 0.0927 (20-44) 0.1559 (45-54) 0.2432 (55-64) 0.3555 (65-74) 0.5294 (75-84) 0.7294 (>=85)	(1)

Contact Matrices

We incorporated four contact matrices in the model; one for each location in the model for which contact between agents can occur. The number of daily contacts per agent was defined by age using projections for Canada from the POLYMOD study (Table S6) (4). Contacts were then distributed amongst agents based on location and defined by four contact matrices also derived from Canadian projections from the POLYMOD study (Tables S7(a) to (d)) (4).

Table S6. Age-dependent daily contact rates, adapted from (4).

Category	Age group	Daily contact rates
Child1	0 to 4	9.0957
Child2	5 to 9	10.5341
Child3	10 to 14	13.0621
Youth	15 to 19	20.3667
Adult1	20 to 44	15.3519
Adult2	45 to 54	14.9039
Adult3	55 to 64	11.0106
Senior1	65 to 74	6.5229
Senior2	75 to 84	4.5929
Elderly	85	4.5929

Transmission probability (β) calibration

The transmission probability parameter was calibrated by fitting cumulative clinical cases from the model to domestically-acquired Canadian cases per 100,000 from February 20 to March 26, 2020 using a simulation optimization engine in AnyLogic. The three-week delay in data fitting was due to restrictions on optimization on integers. The end date was selected as we assumed the impact of community closures in mid-March would be observed after March 26 and the goal was to determine the natural transmission of SARS-CoV-2 in Canada prior to restrictive public health intervention. The model was calibrated to the Canadian data assuming 20% of cases were detected and isolated during their mild symptomatic period and 50% of contacts of the 20% of cases detected were identified and quarantined to account for estimated intervention efforts in Canada over this period (39). The calibrated transmission probability per contact value when applied to the contact matrices in the model and the average duration of infectiousness returns an estimated R_0 of 2.7 at the beginning of the outbreak in Canada. This is consistent with other studies (40). We assumed susceptibility was uniform across age groups due to the current lack of evidence on this phenomenon, for this reason, we fitted the transmission parameter uniformly across all age groups.

Table S7. Contact matrices for a) home, b) school, c) workplace and d) mixed age venues, adapted from (4).

a) Home

		0-4	5-9	10-14	15-19	20-44	45-54	55-64	65-74	75-84	85+
		X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
0-4	X1	0.185268924	0.136841211	0.062772461	0.026486915	0.531074593	0.03755945	0.015109835	0.003183077	0.000851768	0.000851768
5-9	X2	0.079574435	0.248676333	0.108828251	0.034129466	0.467304082	0.048113943	0.009440427	0.002962686	0.000485188	0.000485188
10-14	X3	0.033961819	0.102913604	0.37182724	0.096565139	0.302666114	0.079605258	0.007342565	0.004159194	0.000479533	0.000479533
15-19	X4	0.017385409	0.034227758	0.12479159	0.367875165	0.244262838	0.187289277	0.018563829	0.004803152	0.000400491	0.000400491
20-44	X5	0.113845916	0.122409498	0.097124589	0.070114248	0.481927257	0.078010985	0.030122423	0.005147394	0.000648845	0.000648845
45-54	X6	0.044172607	0.061014183	0.114531315	0.167415659	0.244274449	0.323341426	0.03645493	0.004878245	0.001958592	0.001958592
55-64	X7	0.083402037	0.078014699	0.057054872	0.07080258	0.276447468	0.08018985	0.325864426	0.027005	0.000609534	0.000609534
65-74	X8	0.052446418	0.100139912	0.09313197	0.064808552	0.258083077	0.060366748	0.073748958	0.281306523	0.007983922	0.007983922
75-84	X9	0.063506226	0.077012341	0.121626883	0.095200131	0.21448991	0.177675224	0.053772675	0.065268719	0.065723945	0.065723945
85+	X10	0.063506226	0.077012341	0.121626883	0.095200131	0.21448991	0.177675224	0.053772675	0.065268719	0.065723945	0.065723945

b) School

		0-4	5-9	10-14	15-19	20-44	45-54	55-64	65-74	75-84	85+
		X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
0-4	X1	0.667455938	0.102112522	0.019015295	0.025222437	0.140713216	0.035820713	0.009659879	0	0	0
5-9	X2	0.093550235	0.74692461	0.043109234	0.005861935	0.077623144	0.027317591	0.005613251	0	0	0
10-14	X3	0.000609077	0.126442172	0.761358414	0.029027584	0.052282537	0.023829317	0.006450899	0	0	0
15-19	X4	0.002700024	0.004018615	0.175545221	0.745851841	0.045619098	0.020741558	0.005523643	0	0	0
20-44	X5	0.047182146	0.139244496	0.092980462	0.307656708	0.345093209	0.052082954	0.015760025	0	0	0
45-54	X6	0.086538354	0.176213291	0.188880134	0.364729195	0.107361531	0.06051167	0.015765826	0	0	0
55-64	X7	0.123645408	0.199257947	0.166457593	0.288427887	0.130244678	0.052309999	0.039656489	0	0	0
65-74	X8	0	0	0	0	0	0	0	0	0	0
75-84	X9	0	0	0	0	0	0	0	0	0	0
85+	X10	0	0	0	0	0	0	0	0	0	0

c) Workplace

		0-4	5-9	10-14	15-19	20-44	45-54	55-64	65-74	75-84	85+
		X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
0-4	X1	0	0	0	0	0	0	0	0	0	0
5-9	X2	0	0	0	0	0	0	0	0	0	0
10-14	X3	0	0	0	0	0	0	0	0	0	0
15-19	X4	0	0	0	0.230344513	0.609452032	0.135180423	0.025020481	2.5502E-06	0	0
20-44	X5	0	0	0	0.050490031	0.708783724	0.20152575	0.039198385	2.11074E-06	0	0
45-54	X6	0	0	0	0.045763147	0.612394359	0.282820703	0.059019454	2.33625E-06	0	0
55-64	X7	0	0	0	0.037551598	0.610427672	0.267233687	0.084779535	7.50828E-06	0	0
65-74	X8	0	0	0	0.041277242	0.504506081	0.24778632	0.180746366	0.025683991	0	0
75-84	X9	0	0	0	0	0	0	0	0	0	0
85+	X10	0	0	0	0	0	0	0	0	0	0

d) Mixed age venues

		0-4	5-9	10-14	15-19	20-44	45-54	55-64	65-74	75-84	85+
		X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
0-4	X1	0.168139804	0.073182455	0.037321849	0.031165597	0.401946649	0.118595541	0.101926314	0.057947786	0.004887003	0.004887003
5-9	X2	0.073632396	0.278855522	0.101848468	0.031936905	0.314583842	0.07404201	0.075324436	0.040830057	0.004473181	0.004473181
10-14	X3	0.019946287	0.106621397	0.375858913	0.066411771	0.262526143	0.086224369	0.041503389	0.030674833	0.005116449	0.005116449
15-19	X4	0.008794229	0.027834342	0.129072814	0.437577757	0.291204474	0.068153243	0.021106225	0.013213285	0.001521815	0.001521815
20-44	X5	0.024976547	0.023353486	0.02849828	0.074076533	0.610138038	0.133566987	0.067573564	0.031134162	0.003341201	0.003341201
45-54	X6	0.011246284	0.020290879	0.024054085	0.044471599	0.473232159	0.239180085	0.12707165	0.051900294	0.004276483	0.004276483
55-64	X7	0.015610564	0.01520968	0.014876674	0.022550805	0.436932485	0.183184314	0.205882008	0.095600726	0.005076372	0.005076372
65-74	X8	0.010953225	0.016417351	0.014351632	0.023580045	0.358445882	0.164433878	0.213938798	0.180408283	0.008735454	0.008735454
75-84	X9	0.015412188	0.015768683	0.023208638	0.014490252	0.315027559	0.183117471	0.166447925	0.205473912	0.030526687	0.030526687
85+	X10	0.015412188	0.015768683	0.023208638	0.014490252	0.315027559	0.183117471	0.166447925	0.205473912	0.030526687	0.030526687

Baseline calibration to Canadian data and public health interventions applied in Canada

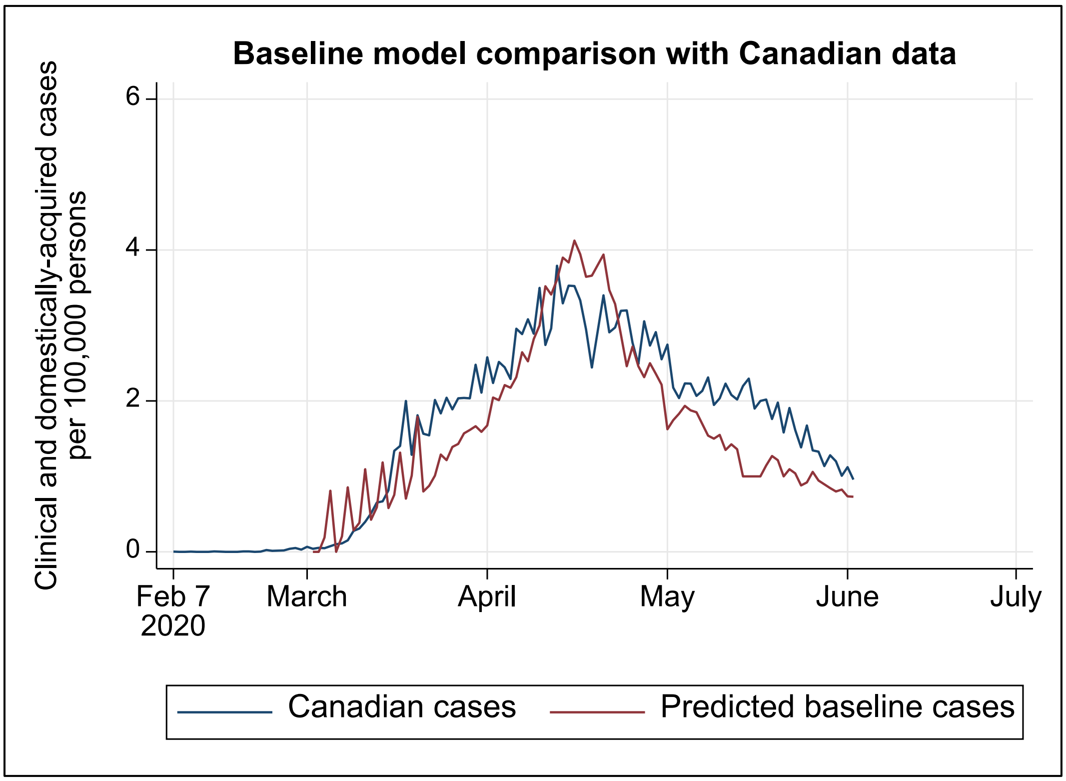
The first 94 days in the model represents the Canadian baseline (February 7 to May 10, 2020). This is the period in which we initially observe community transmission in Canada and case detection, isolation and contact tracing is applied from the onset. By mid-March (March 16, 2020), heavy restrictions are put in place with the closure of schools and non-essential businesses in many provinces and territories. In the baseline scenario, these closures are lifted on Monday, May 11, 2020; though we recognise some provinces and territories lifted much earlier while others are still in the early stages of re-opening. The baseline assumes the following non-pharmaceutical interventions have been applied for the first 94 days, these are based on data (which are referenced below) or are estimated:

- 20% of symptomatic cases are identified via contact tracing and isolated for their remaining infectious period – based on the estimated number of symptomatic cases believed to be reported in Canada derived from mortality rate, the estimate has changed from 31% (March) to 17% (April) (39)
- 50% of household members of identified cases also co-isolate (estimate)
- 50% of those exposed by the 20% symptomatic cases detected are identified via contact tracing and quarantined before they are infectious (estimate)
- 100% of schools, 40% of workplaces and 50% of mixed age meeting venues are closed for an 8-week period from March 16 to May 10, 2020) – based on the combined averages for Canada from four Google Mobility reports dated March 29, April 11, April 26 and May 9 that cover this 8-week period (41, 42)

In addition, we assume there has also been a general 20% reduction in contact rate as a result of personal physical distancing (estimate) but supported by survey data (43, 44). We did not apply a higher reduction in contact rate because in the model, the closures already account for a reduction in contacts in agents who are regularly in contact with each other. As it is difficult to separate out the reduction in contact due to closures, we estimated a general 20% reduction in contact rate in addition to reduction in contacts because of closures. Physical distancing is only applied outside of the household.

Figure S2 compares the mean daily incidence from 200 model runs (50 each from Scenarios 1 to 4) during the baseline period (February 7 to May 10, 2020) to the Canadian incidence data (February 7 to June 2, 2020), in particular, we compare predicted clinical cases to locally acquired reported cases not associated with long-term care facility outbreaks and hospital transmission. The Canadian data are provided to PHAC from the provinces and territories and cases are presented by their date of onset in Figure S2. We calculated the root-mean-squared error (RMSE) to quantify the model fit to Canadian data. The lowest RMSE value (0.55278) was observed at a 23-day lag between the predicted cases and the observed cases. The 23-day delay is primarily due to the conversion of Canadian cases to cases per 100,000 persons which explains the lengthy burn-in period that is not observed in the model. However, the model is a fairly accurate representation of the overall Canadian situation with the peak occurring just before restrictive measures are put in place peaking at 4 clinical cases per 100,000 in the model, this corresponds to the peak in domestically-acquired Canadian cases at the peak of the current wave (1,422 new cases reported on April 13; ~3.8 cases per 100,000). Contributing to the delay may be recall bias on the onset date. We note that the onset date was missing for approximately 25% of cases, the date of report lagged by 7 days was used as a proxy for the presumed onset date for these cases. For the last three weeks of the time series, the status of patients that were associated with long-term care facility outbreaks and hospital transmission were no longer available so some of these cases remain in the Canadian dataset thus contributing to a larger difference between the observed and predicted values.

Figure S2 Comparison between locally-acquired Canadian cases by onset date and the predicted clinical cases in the baseline scenario with a 23-day lag. We assume community transmission in Canada began on February 7, 2020.



Interpreting the outputs of the agent-based model

Agent-based models are well suited for modelling events that occur by chance, for this reason, we have developed a SARS-CoV-2 transmission model using agent-based simulation. By chance, an infected agent can instigate an outbreak that spreads widely in the population (as has been seen in multiple countries with imported cases returning) but in the same modelling simulation, we may not observe secondary cases caused by an the infected agent (also likely to occur in reality but is unknown). The dichotomy in outcome in the agent-based model is more likely to be observed in scenarios in which enhance measures are applied and in which there are a small number of agents infected. Because of the range in outcomes that can be observed in the same scenario, we present our results as median values with the 2.5^{th} percentile and 97.5^{th} percentile presented as 95% credible intervals. The 95% credible intervals are therefore asymmetrical and the wider the 95% credible interval, the more dichotomous the outcomes were across the 50 realizations. In contrast, in scenarios where an outbreak is likely to occur (for example, the no intervention scenario), the credible intervals will be closer to the median indicating the outcome across the 50 realizations were all similar, i.e. there is more certainty in the results. Therefore, we may see some model scenarios with estimates that are very precise, these outcomes indicate a scenario that will produce an outcome that is reliable and reproducible. There are two scenarios when this will occur, when the intervention levels are set extremely high so that infected agents are unable to infected other agents in the population (extinction is observed 100% of the time) or in the no intervention scenario, where agents will continue to infected each other until herd immunity is reached in the population, in this case, ~65% of the population.

Exploring the impact of interventions on their own

Figure S3. No intervention model. Severe cases are assumed to stay home and self-isolate and are therefore not considered a source for community transmission (but can be a source for household transmission; household contacts are reduced by 50% for agents in self-isolation). Final total attack rate of 64.6% (95% CI, 63.9%-65.0%).

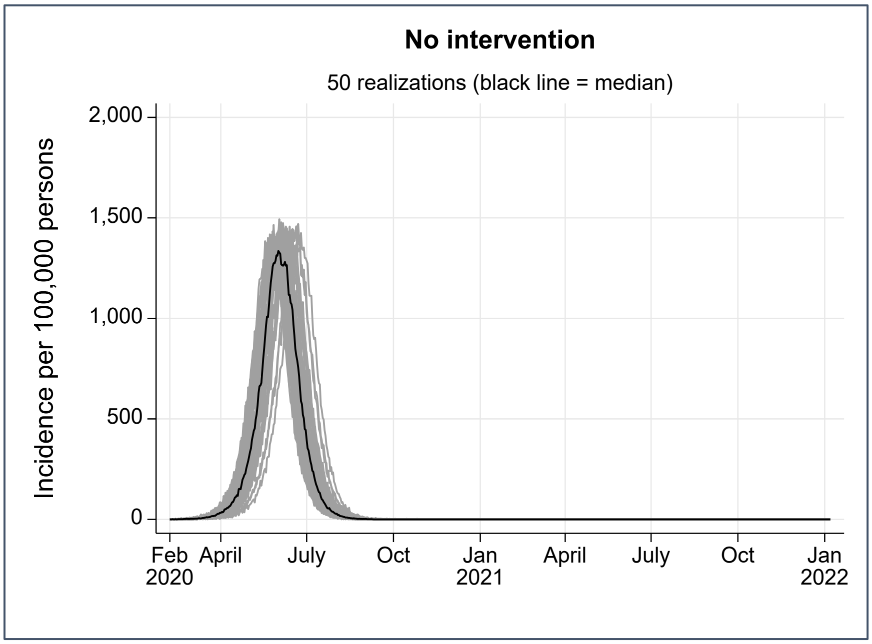


Figure S4. Model with partial community closure (100% of schools, 40% of workplaces and 50% of mixed age venues) applied on March 16, 2020 (day 38) and remaining active for the remaining model run (day 700); total duration of 662 days. The shaded green area indicates the period in which closure is in place). Final total attack rate of 7.6% (95% CI, 0.36-13.2%).

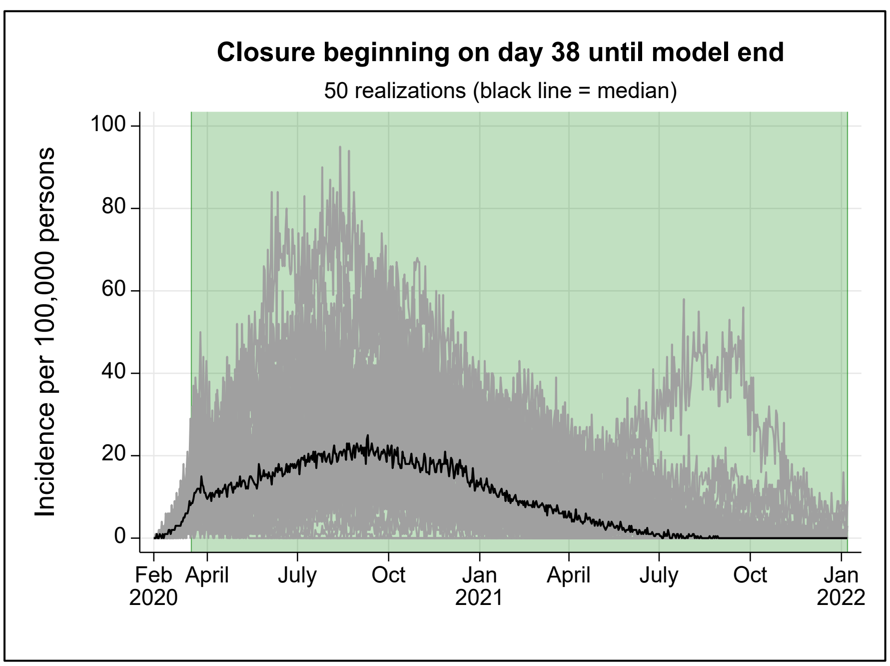


Figure S5. Model with sustained personal physical distancing resulting in a 20% reduction in contact rate when outside of the household. Intervention is active for the duration of the model run. Final total attack rate of 54.0% (95% CI, 53.0%-54.8%).

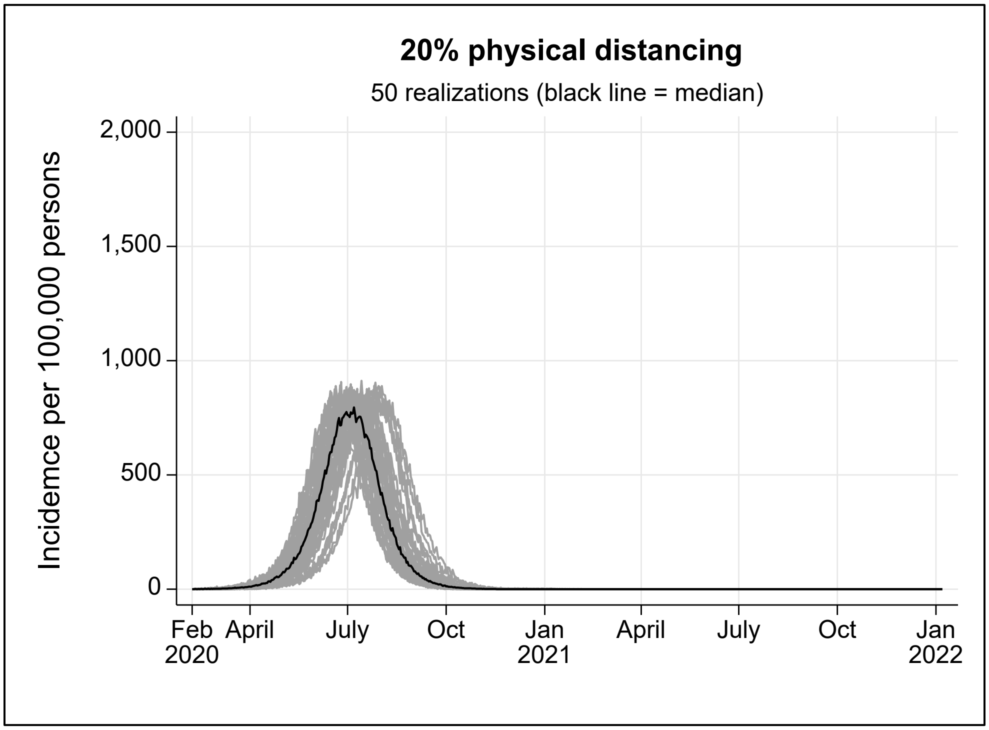


Figure S6. Model identifying 20% of sick individuals and placing them in isolation for the remainder of their infectious period. 50% of household members co-isolate. Intervention is active for the duration of the model run. Final total attack rate of 59.3% (95% CI, 0.04%-60.0%).

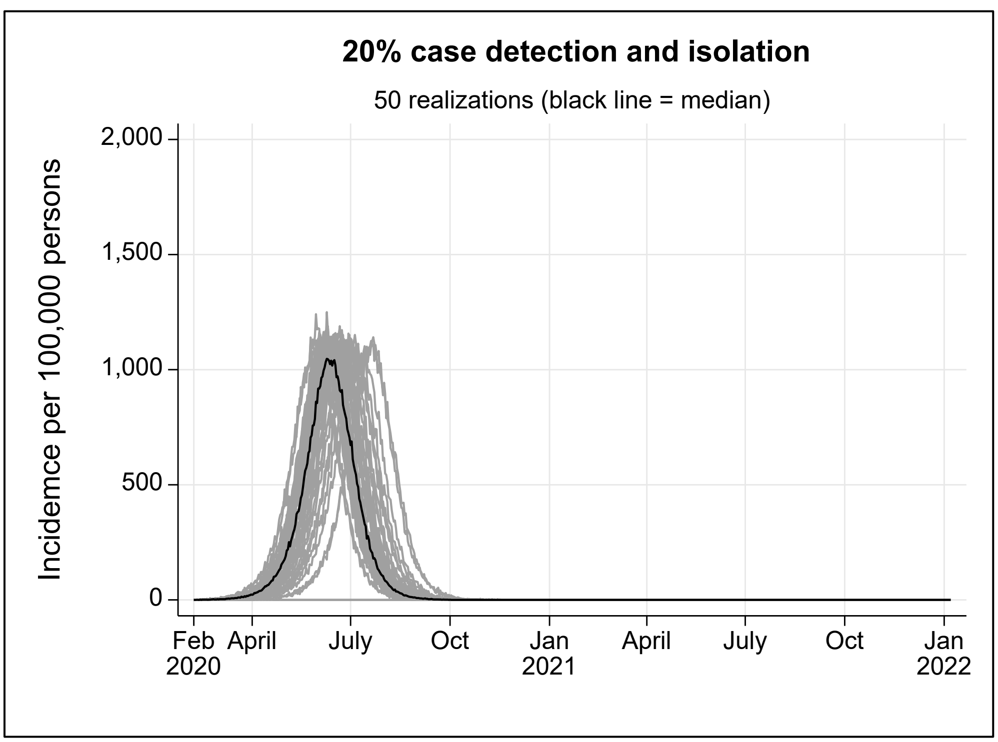


Figure S7. Model identifying 50% of exposed individuals via contact tracing (of 20% of cases detected) and placing them in quarantine before they are infectious. Intervention is active for the duration of the model run. Final total attack rate of 62.5% (95% CI, 62.0%-63.3%).

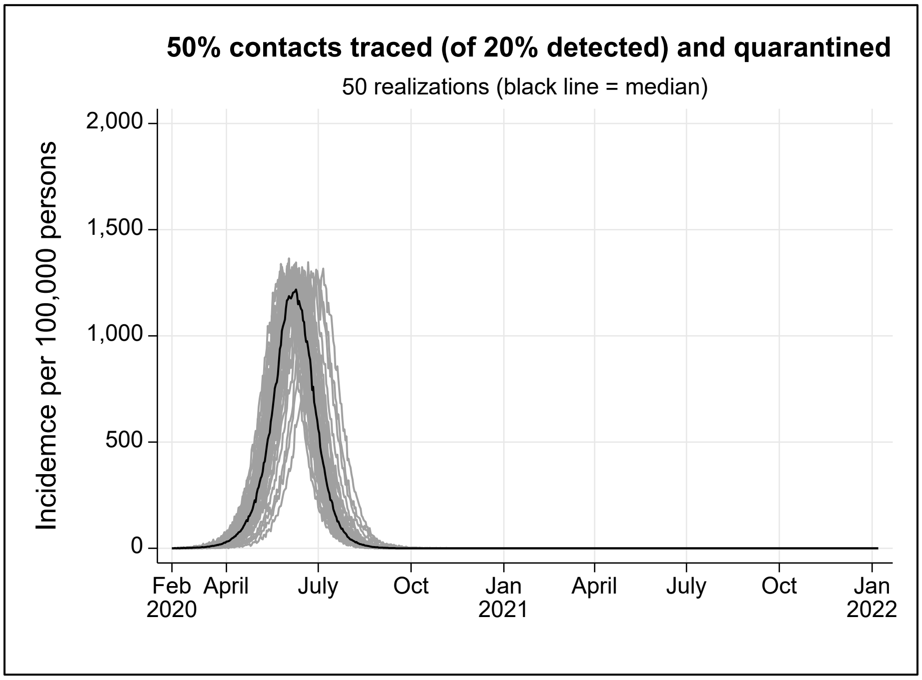


Figure S8. Model with 20% cases detected and isolated with 50% household co-isolation, 50% of contacts of the 20% cases detected traced and quarantined and 20% contact rate reduction due to physical distancing. Interventions are active for the entire duration of the model run. Final total attack rate of 42.3% (95% CI, 0.03%-43.3%).

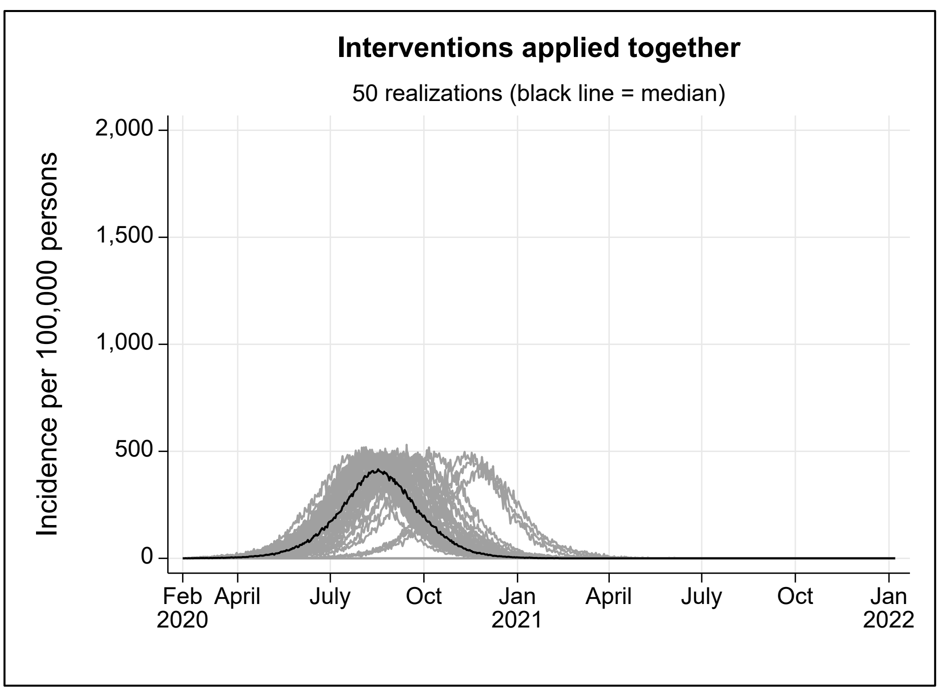


Figure S9. Projected hospitalization bed utilization showing daily hospitalization prevalence per 100,000 persons for Scenarios 1 (minimal control), 2 (maintained physical distancing), 3 (enhanced case detection and contact tracing) and 4 (combined interventions) with extended school closure. Prevalent cases include those requiring general hospitalization in addition to those requiring pre-ICU and post-ICU hospitalization resulting from COVID-19. The maximum Canadian hospital capacity is represented by the dashed horizontal red lines. Median values are represented by the black line. Each grey line represents one model realization out of a total of 50 per scenario.

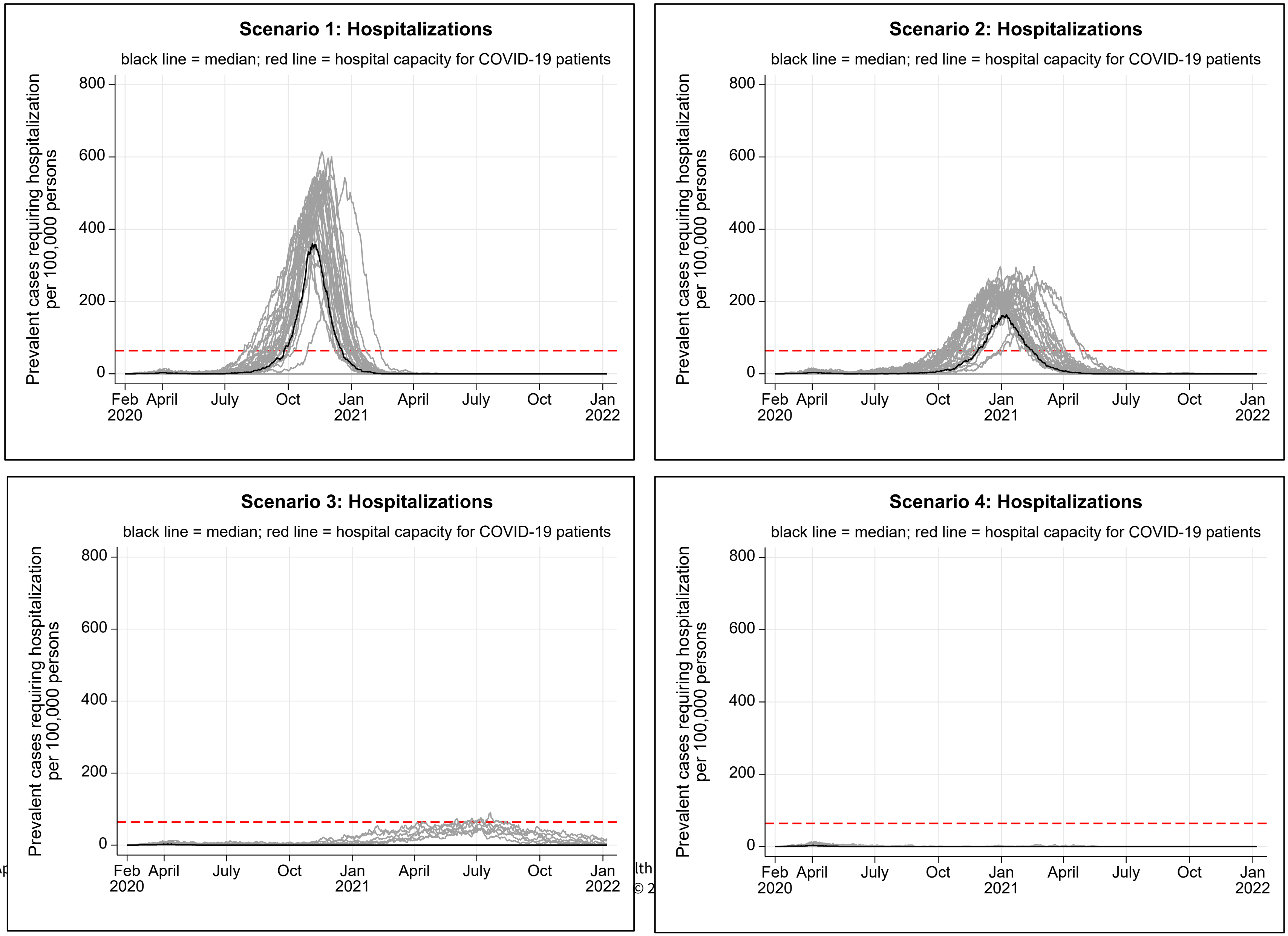


Figure S10. Projected ICU bed utilization showing daily ICU prevalence per 100,000 persons for Scenarios 1 (minimal control), 2 (maintained physical distancing), 3 (enhanced case detection and contact tracing) and 4 (combined interventions) with extended school closure. The maximum Canadian ICU bed capacity is represented by the dashed horizontal red lines. Median values are represented by the black line. Each grey line represents one model realization out of a total of 50 per scenario.

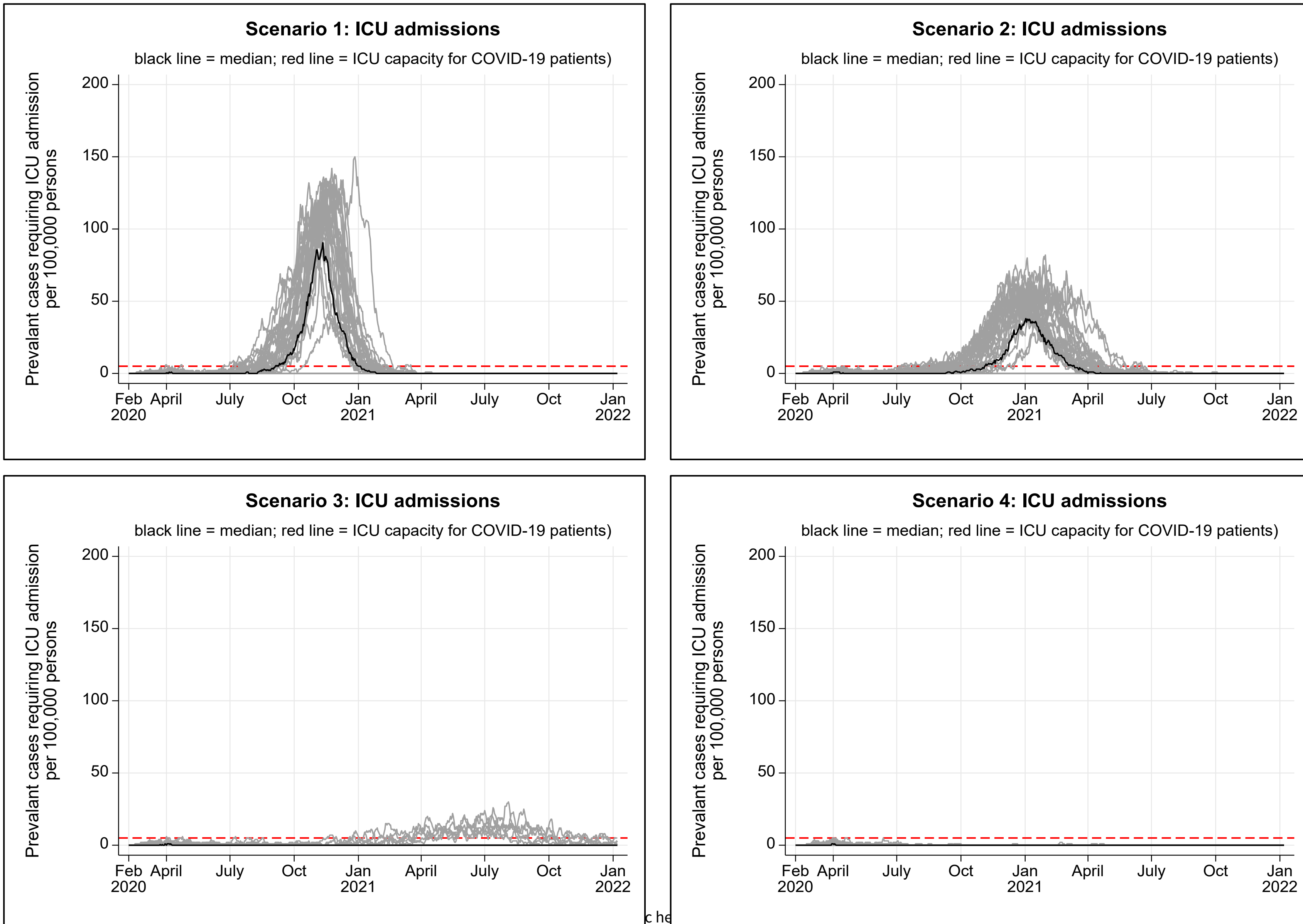


Figure S11. Projected hospitalization bed utilization showing daily hospitalization prevalence per 100,000 persons for Scenarios 1 (minimal control), 2 (maintained physical distancing), 3 (enhanced case detection and contact tracing) and 4 (combined interventions) with extended workplace and mixed age venue closures. Prevalent cases include those requiring general hospitalization in addition to those requiring pre-ICU and post-ICU hospitalization resulting from COVID-19. The maximum Canadian hospital capacity is represented by the dashed horizontal red lines. Median values are represented by the black line (the majority of realizations in these scenarios did not result in an outbreak, the median values sit on 0). Each grey line represents one model realization out of a total of 50 per scenario.

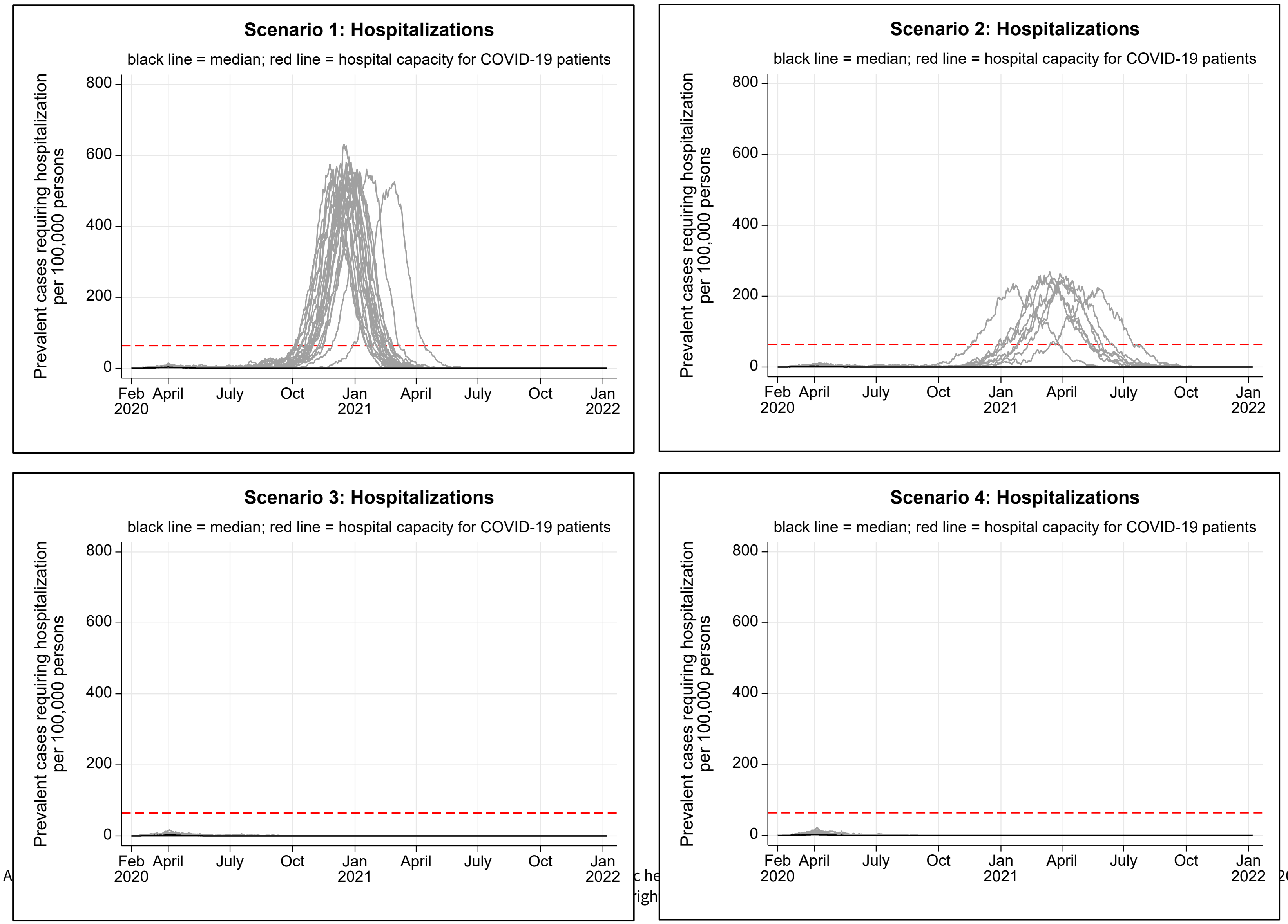
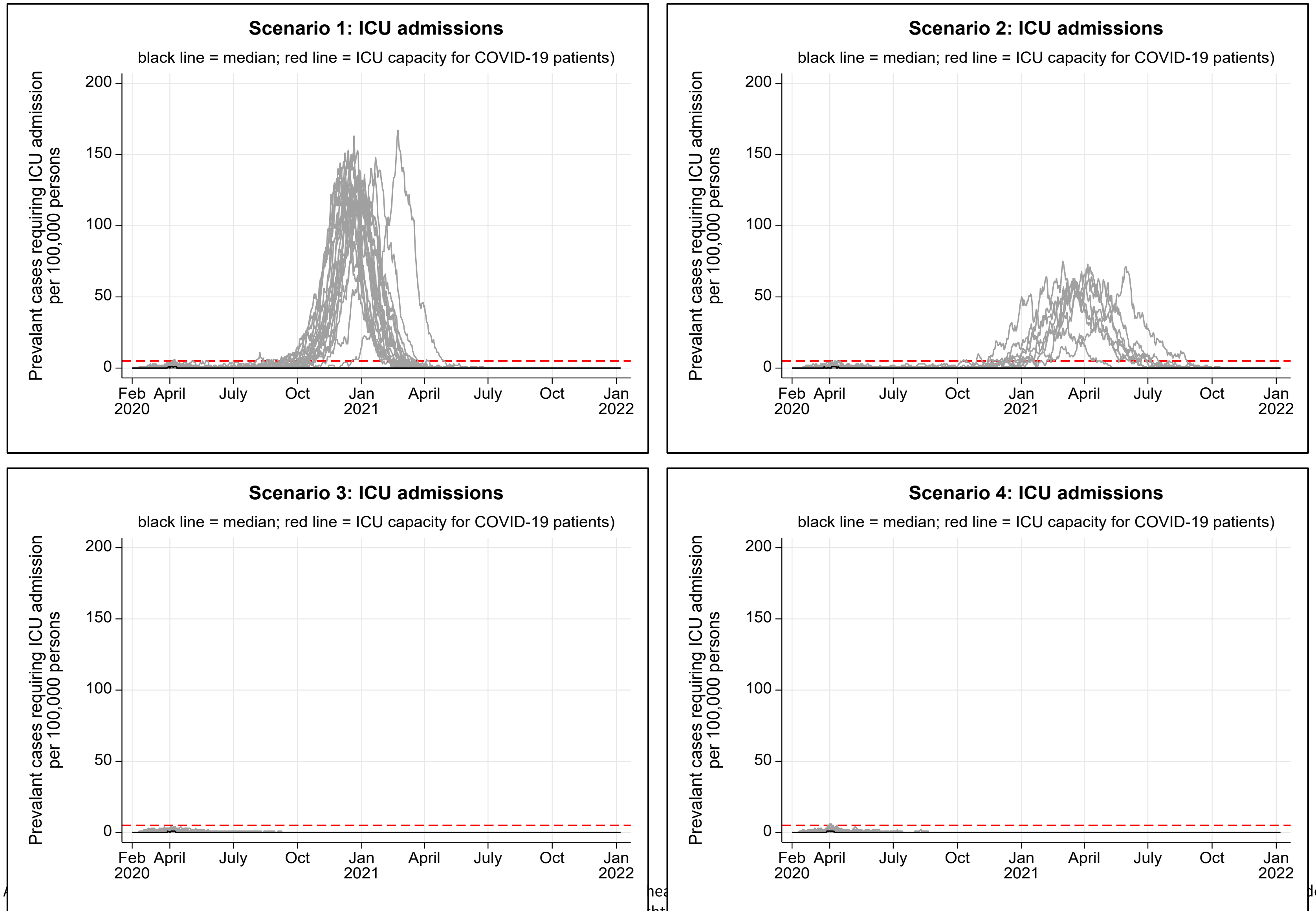


Figure S12. Projected ICU bed utilization showing daily ICU prevalence per 100,000 persons for Scenarios 1 (minimal control), 2 (maintained physical distancing), 3 (enhanced case detection and contact tracing) and 4 (combined interventions) with extended school closure. The maximum Canadian ICU bed capacity is represented by the dashed horizontal red lines. Median values are represented by the black line (the majority of realizations in these scenarios did not result in an outbreak, the median values sit on 0). Each grey line represents one model realization out of a total of 50 per scenario.



Sensitivity Analyses

We present a sensitivity analysis on the transmission parameter (β) by modifying β to explore the impact this parameter has on case incidence and prevalence of hospital and ICU bed utilization with the public health interventions applied in the 4 scenarios (Table 2). Figures S13 to S16 show the degree to which β has an impact on epidemic trajectory. Figures S17 to S19 show the range in impact β would have on our healthcare system in terms of hospital beds and Figures S20 to S24 show the impact β would have on ICU bed utilization. To summarize:

1. With R_0 = 2.0 (β=0.0303), minimal control resulted in the elimination of the epidemic in most realizations, an endemic state of transmission in some realizations under maintained physical distancing, and epidemic elimination with enhanced case detection and contact tracing and combined interventions. Hospital and ICU bed utilization were within capacity under all scenarios except minimal control. Only in some realizations under minimal control are hospital and ICU bed utilizations projected to be over capacity.
2. With R_0 = 2.4 (β=0.0364), half of the realizations under minimal control resulted in an epidemic, while just under half under maintained physical distancing resulted in an epidemic; these realizations are projected to utilize more hospital and ICU beds than available. Enhanced case detection and contact tracing and combined interventions are projected to be sufficient to control the epidemic and hospital and ICU bed utilizations are projected to be within what is available.
3. With R_0 = 2.7 (β=0.0393), our estimated R_0 according to the initial trajectory of community transmission in Canada, the minimal control and maintained physical distancing scenarios indicate the interventions applied are not sufficient to control an epidemic once restrictive measures are lifted. The enhanced case detection and contact tracing scenario indicates the interventions applied are sufficient to control the epidemic in over half of the realizations but may not be enough for the remaining realizations, i.e. there is some uncertainty as to whether enhanced case detection and contact tracing issufficient to control an epidemic. Only under combined interventions were the interventions sufficient to control the epidemic; but some realizations indicate control may not occur until Fall 2021. Accordingly, hospital and ICU bed utilizations under minimal control and maintained physical distancing are projected to be over capacity, there is some uncertainty with resources under enhanced case detection and contact tracing but no anticipated shortage of resources if combined interventions are applied.
4. With R_0 = 3.0 (β=0.0454), it is anticipated the levels of interventions applied in all four scenarios are insufficient to eliminate an epidemic. Hospital bed utilization may be within current capacity only under combined interventions while ICU bed utilization is anticipated to be just at capacity. All other scenarios indicate a shortage of hospital and ICU beds unless restrictive measures are reimplemented.

The sensitivity analysis indicates that the model results are dependent on β. Studies indicate that R_0 for SARS-CoV-2 is likely to be between 2.4 and 3.0 (40), which is higher than the R_0 for seasonal influenza. Our analysis suggests only under enhance control measures (Scenarios 3 and 4) can we control the epidemic with certainty across a range of β values; the occasional implementation of restrictive closures may be necessary to prevent overwhelming our healthcare system. Comprehensive tables of the model outputs from the sensitivity analysis is presented in Appendix 2 (Tables S5 to S8).

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Figure S13 **Projected epidemic curves showing daily case incidence per 100,000 persons for Scenario 1 (minimal control) with comparison between four R0 values. The green bar represents the period from March 16 to May 10, 2020 corresponding to restrictive closures. These figures show the degree to which modifying R_0 by changing the transmission parameter (β) to 0.0303 (R_0=2.0), 0.0364 (R_0=2.4) and 0.0454 (R_0=3.0) from the fitted value of 0.0393 (R=2.7) modifies epidemic trajectory. Median values are represented by the black line. Each grey line represents one model realization out of 50 per scenario. In the scenario for R_0= 2.0, the median line is not visible because most realizations did not result in an epidemic.**

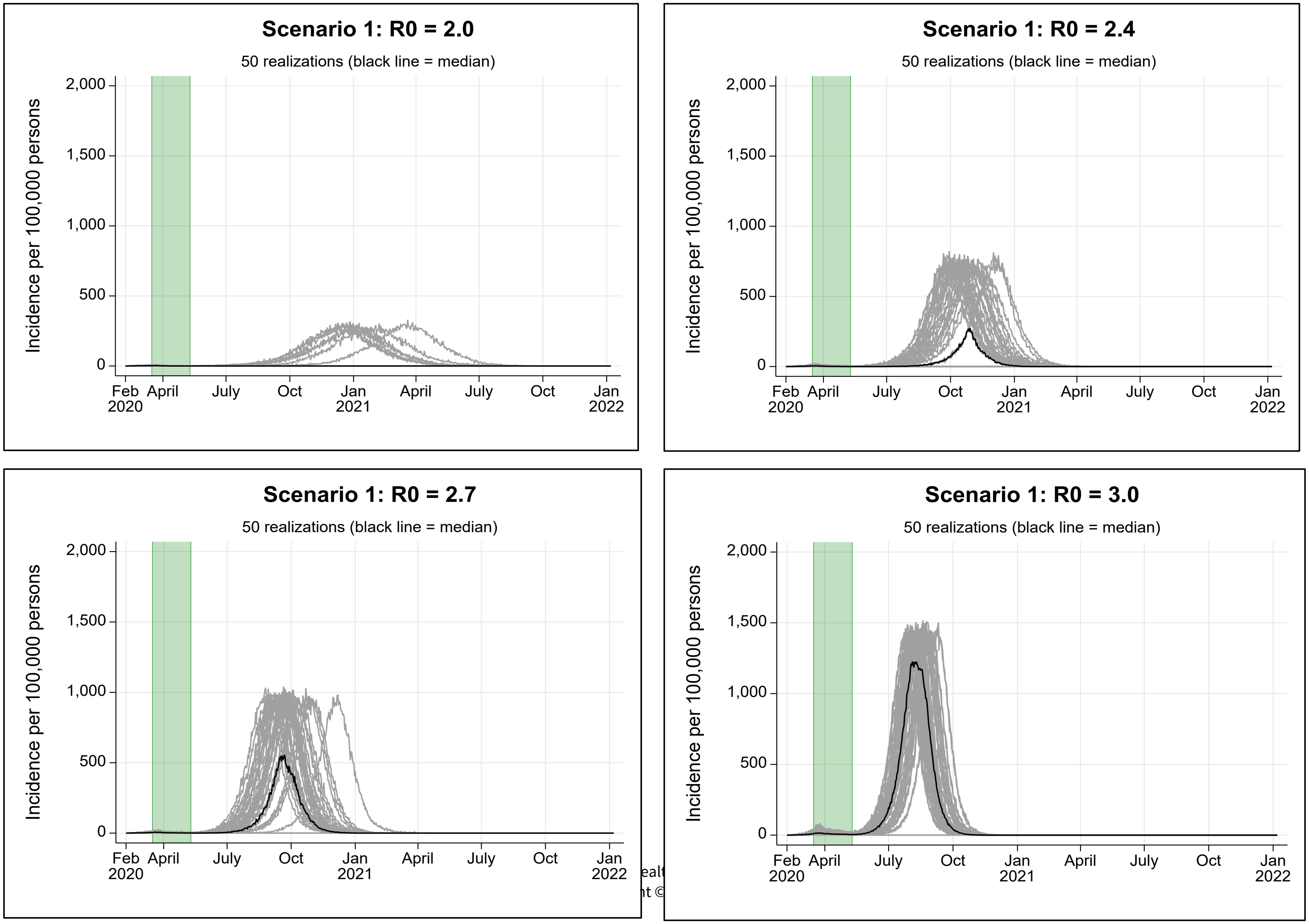


Figure S14 Projected epidemic curves showing daily case incidence per 100,000 persons for Scenario 2 (maintained physical distancing) with comparison between four R0 values. The green bar represents the period from March 16 to May 10, 2020 corresponding to restrictive closures. These figures show the degree to which modifying R_0 by changing the transmission parameter (β) to 0.0303 (R_0=2.0), 0.0364 (R_0=2.4) and 0.0454 (R_0=3.0) from the fitted value of 0.0393 (R=2.7) modifies epidemic trajectory. Median values are represented by the black line. Each grey line represents one model realization out of 50 per scenario. In the R_0= 2.0 scenario, the median line is only visible at the start of the epidemic and the scale is smaller. In the scenario for R_0= 2.4, the median line is not visible because most realizations did not result in an epidemic.

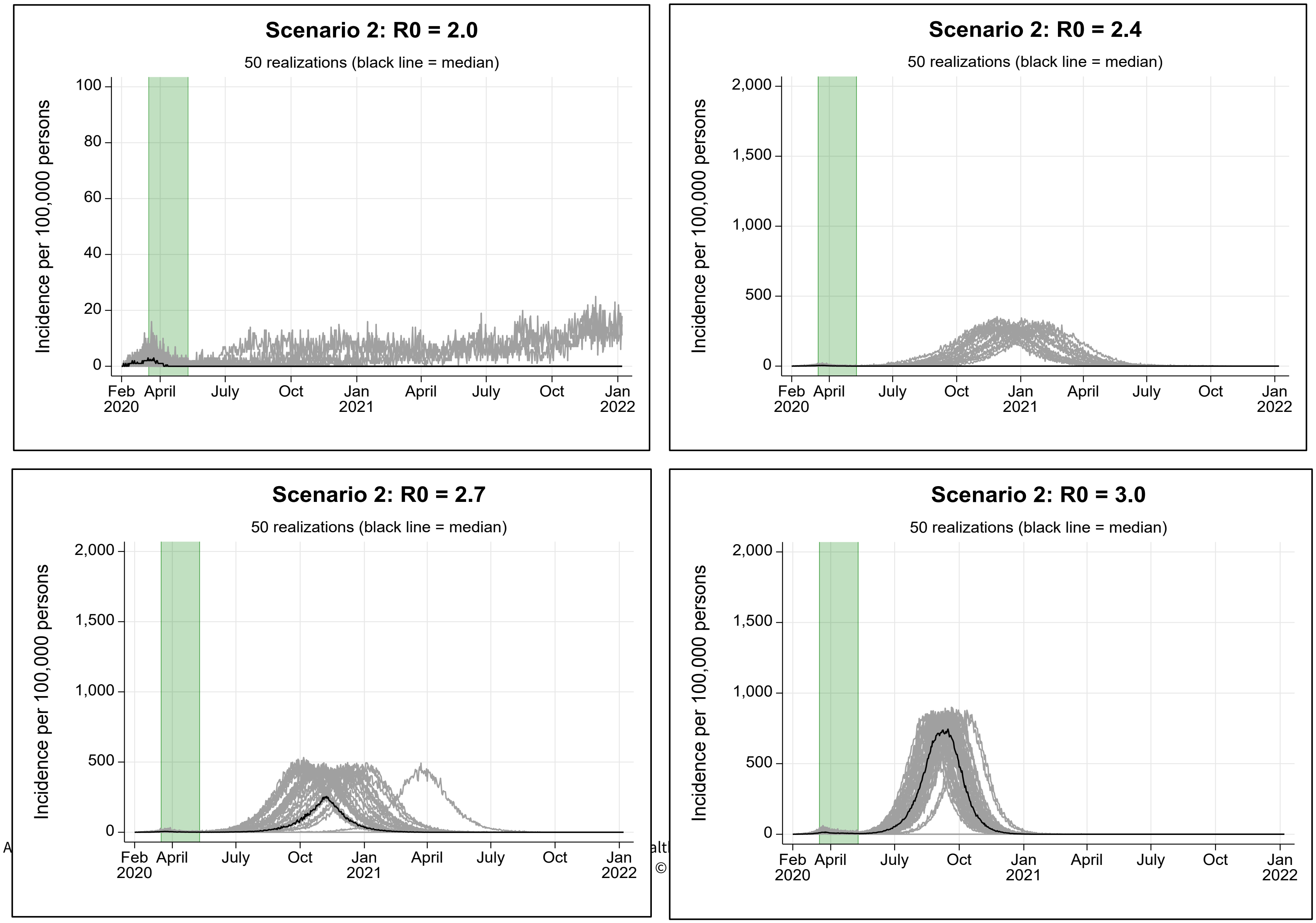


Figure S15 **Projected epidemic curves showing daily case incidence per 100,000 persons for Scenario 3 (enhanced case detection and contact tracing) with comparison between four R0 values. The green bar represents the period from March 16 to May 10, 2020 corresponding to restrictive closures. These figures show the degree to which modifying R_0 by changing the transmission parameter (β) to 0.0303 (R_0=2.0), 0.0364 (R_0=2.4) and 0.0454 (R_0=3.0) from the fitted value of 0.0393 (R=2.7) modifies epidemic trajectory. Median values are represented by the black line. Each grey line represents one model realization out of 50 per scenario. The scale is smaller in the scenarios for R_0= 2.0 and R_0= 2.4. In the scenario for R_0= 2.7, the median line is not visible because most realizations did not result in an epidemic.**

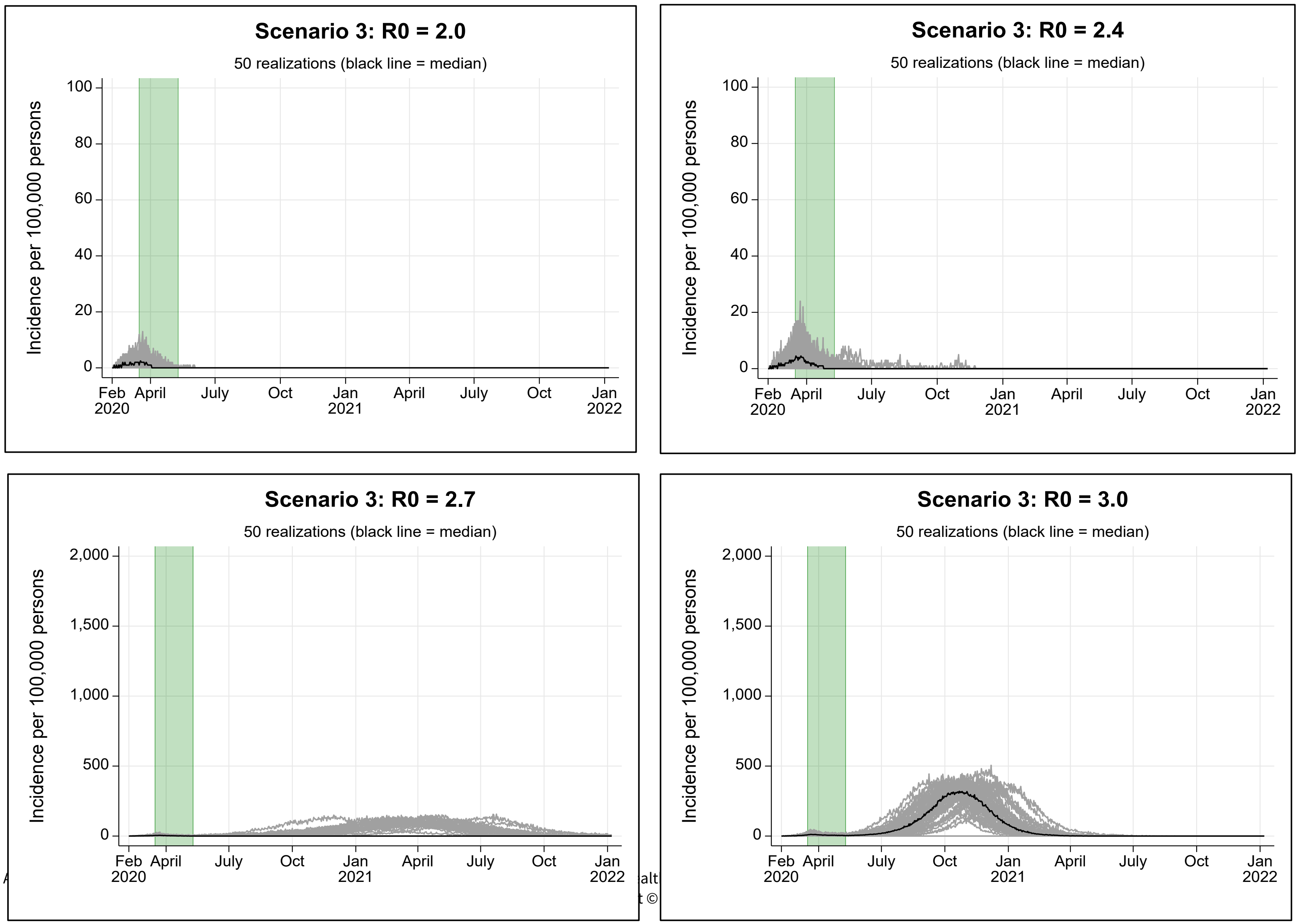


Figure S16 Projected epidemic curves showing daily case incidence per 100,000 persons for Scenario 4 (combined interventions) with comparison between four R0 values. The green bar represents the period from March 16 to May 10, 2020 corresponding to restrictive closures. These figures show the degree to which modifying R_0 by changing the transmission parameter (β) to 0.0303 (R_0=2.0), 0.0364 (R_0=2.4) and 0.0454 (R_0=3.0) from the fitted value of 0.0393 (R=2.7) modifies epidemic trajectory. Median values are represented by the black line. Each grey line represents one model realization out of 50 per scenario. Only in the R_0=3.0 scenario did a large-scale multi-year epidemic occur.

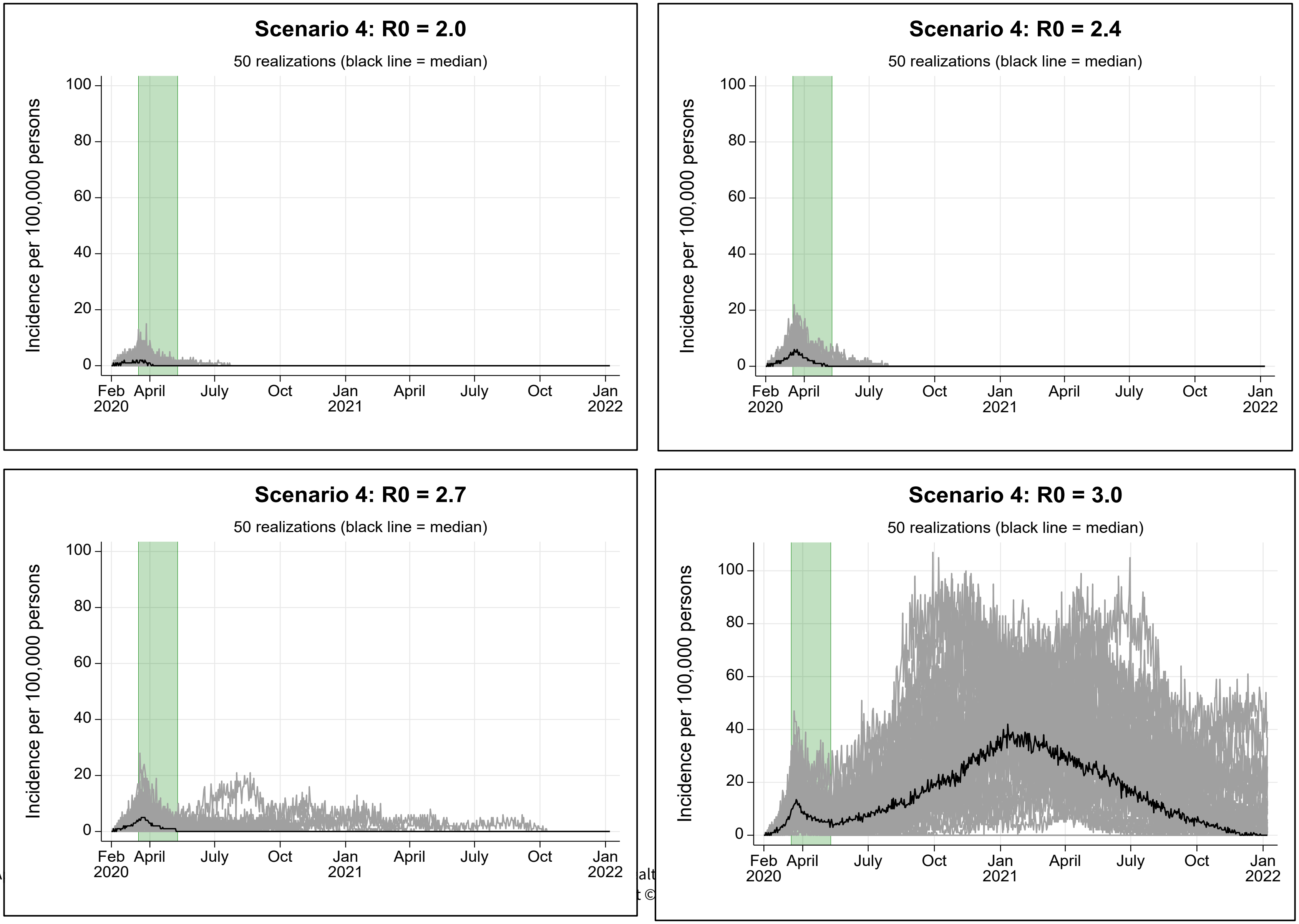


Figure S17. Projected hospitalization bed utilization showing daily hospitalization prevalence per 100,000 persons for Scenario 1 (minimal control) with comparison between four R_0 values. Prevalent cases include those requiring general hospitalization in addition to those requiring pre-ICU and post-ICU hospitalization resulting from COVID-19. The maximum Canadian hospital bed capacity is represented by the dashed horizontal red lines (64 per 100,000 persons). Median values are represented by the black line. Each grey line represents one model realization out of 50 per scenario. Figures show the degree to which modifying R_0 by changing the transmission parameter (β) to 0.0303 (R_0=2.0), 0.0364 (R_0=2.4) and 0.0454 (R_0=3.0) from the fitted value of 0.0393 (R=2.7) has on projected hospital bed utilization.

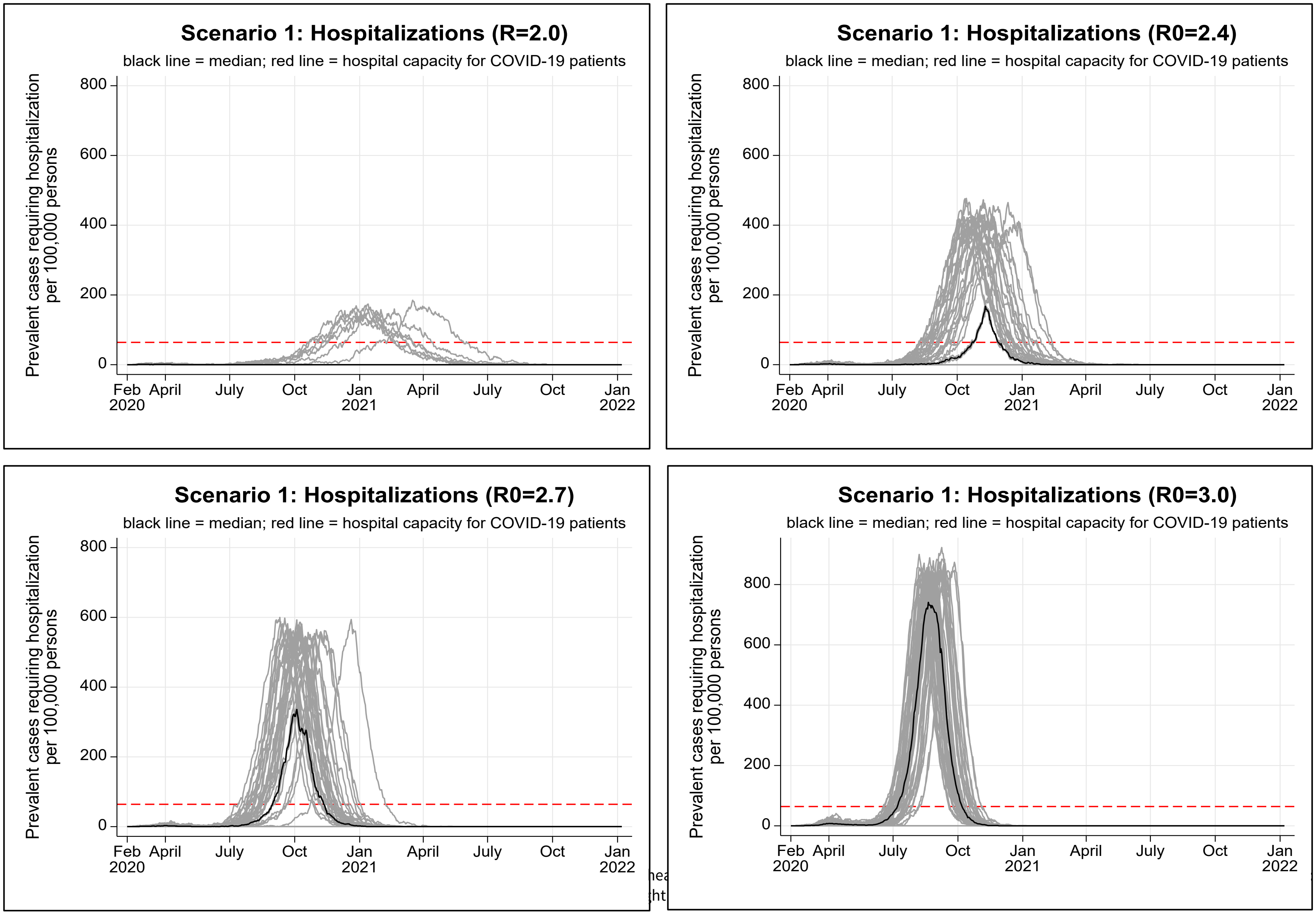


Figure S18. Projected hospitalization bed utilization showing daily hospitalization prevalence per 100,000 persons for Scenario 2 (maintained physical distancing) with comparison between four R_0 values. Prevalent cases include those requiring general hospitalization in addition to those requiring pre-ICU and post-ICU hospitalization resulting from COVID-19. The maximum Canadian hospital bed capacity is represented by the dashed horizontal red lines (64 per 100,000 persons). Median values are represented by the black line. Each grey line represents one model realization out of 50 per scenario. Figures show the degree to which modifying R_0 by changing the transmission parameter (β) to 0.0303 (R_0=2.0), 0.0364 (R_0=2.4) and 0.0454 (R_0=3.0) from the fitted value of 0.0393 (R=2.7) has on projected hospital bed utilization.

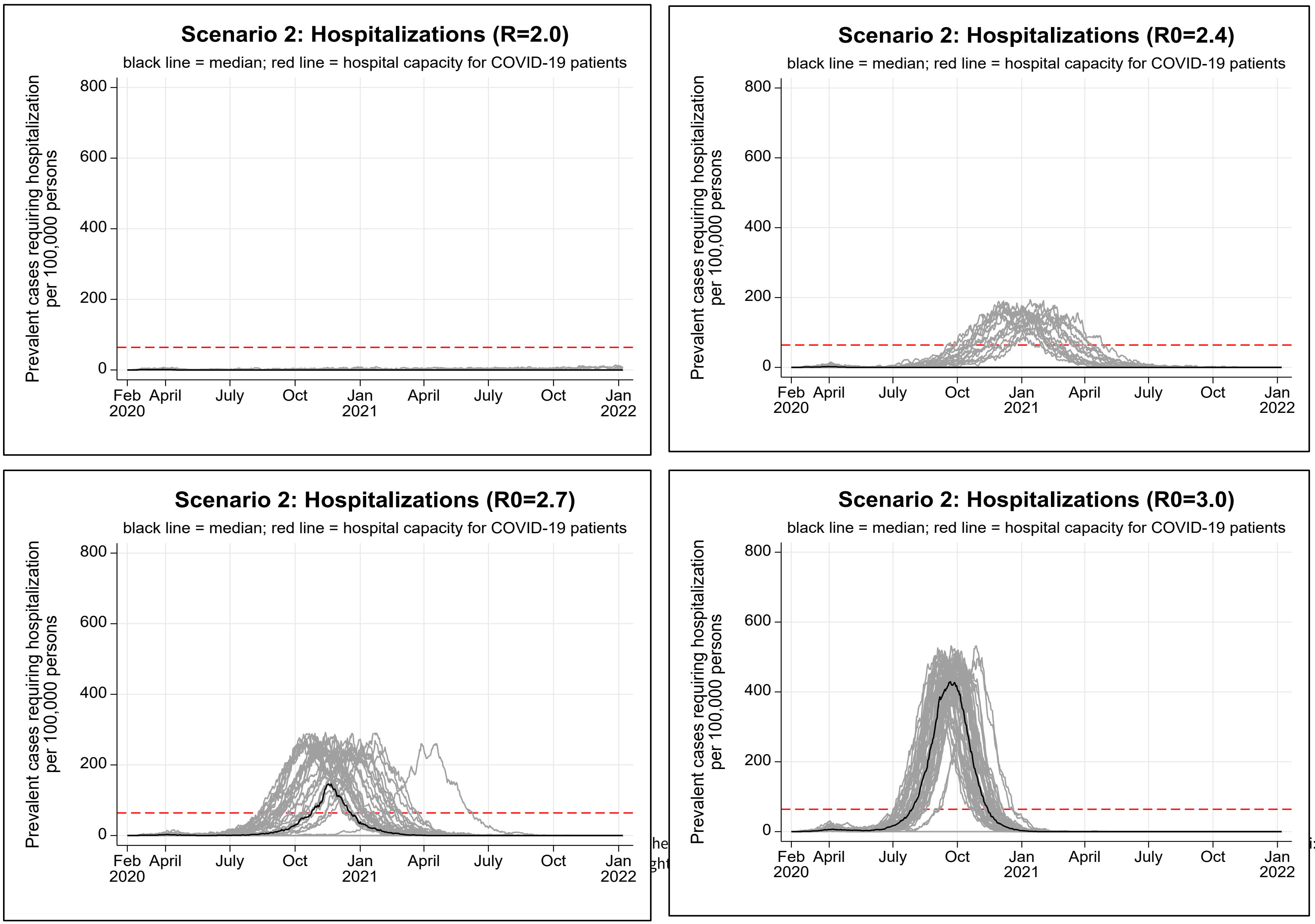


Figure S19. Projected hospitalization bed utilization showing daily hospitalization prevalence per 100,000 persons for Scenario 3 (enhanced case detection and contact tracing) with comparison between four R_0 values. Prevalent cases include those requiring general hospitalization in addition to those requiring pre-ICU and post-ICU hospitalization resulting from COVID-19. The maximum Canadian hospital bed capacity is represented by the dashed horizontal red lines (64 per 100,000 persons). Median values are represented by the black line. Each grey line represents one model realization out of 50 per scenario. Figures show the degree to which modifying R_0 by changing the transmission parameter (β) to 0.0303 (R_0=2.0), 0.0364 (R_0=2.4) and 0.0454 (R_0=3.0) from the fitted value of 0.0393 (R=2.7) has on projected hospital bed utilization.

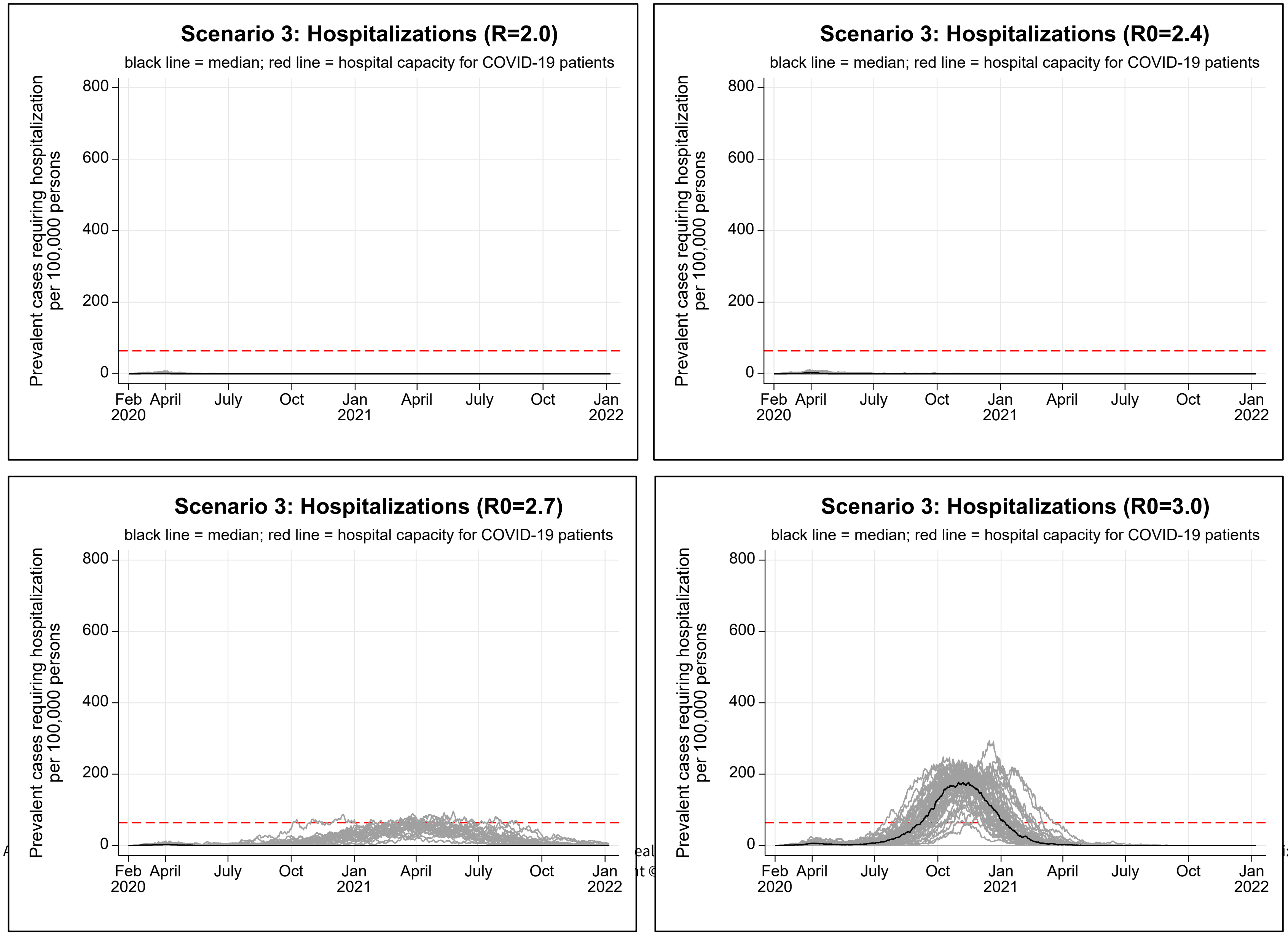


Figure S20. Projected hospitalization bed utilization showing daily hospitalization prevalence per 100,000 persons for Scenario 4 (combined interventions) with comparison between four R_0 values. Prevalent cases include those requiring general hospitalization in addition to those requiring pre-ICU and post-ICU hospitalization resulting from COVID-19. The maximum Canadian hospital bed capacity is represented by the dashed horizontal red lines (64 per 100,000 persons). Median values are represented by the black line. Each grey line represents one model realization out of 50 per scenario. Figures show the degree to which modifying R_0 by changing the transmission parameter (β) to 0.0303 (R_0=2.0), 0.0364 (R_0=2.4) and 0.0454 (R_0=3.0) from the fitted value of 0.0393 (R=2.7) has on projected hospital bed utilization.

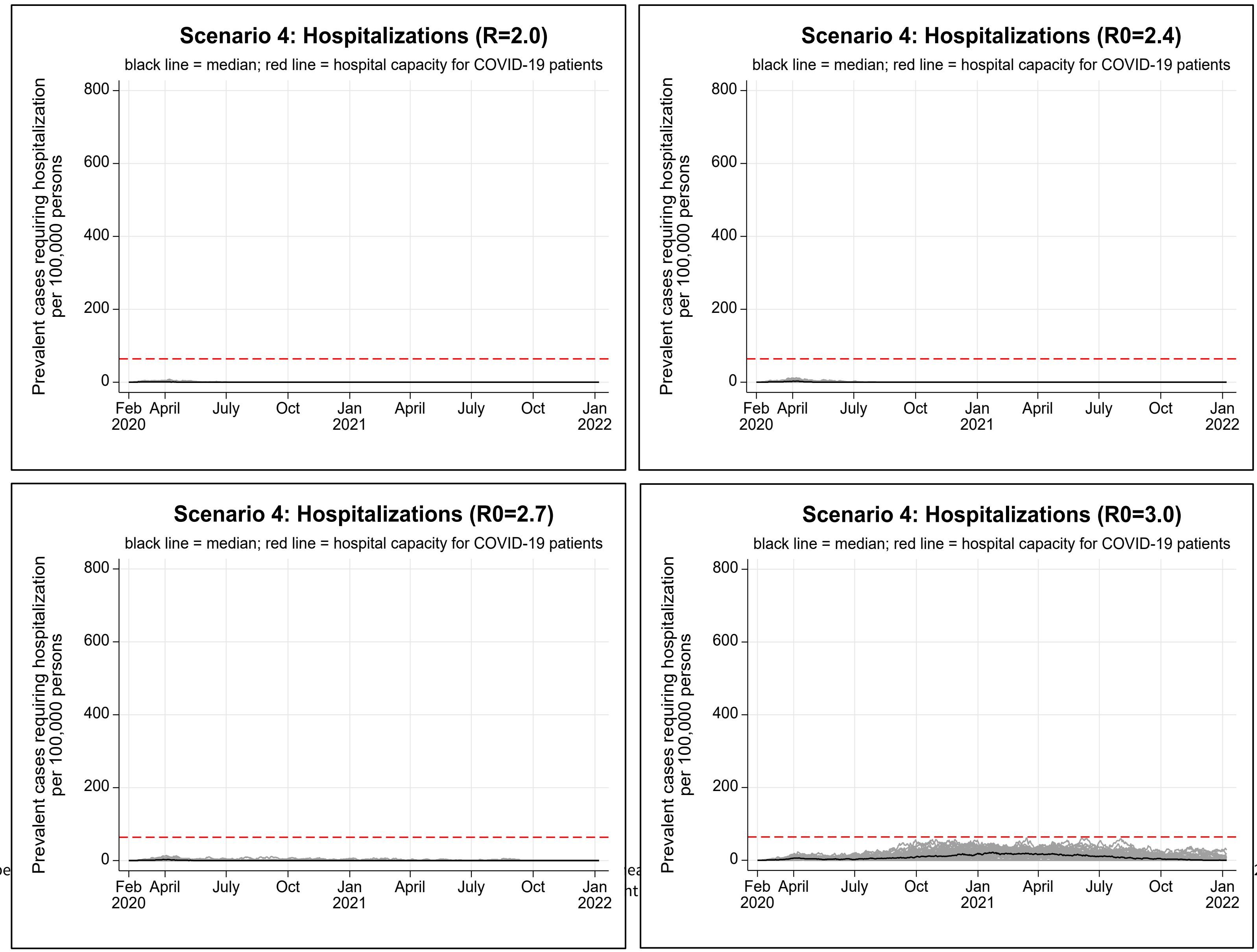


Figure S21. Projected ICU bed utilization showing daily ICU prevalence per 100,000 persons for Scenario 1 (minimal control) with comparison between four R_0 values. The maximum Canadian ICU bed capacity for COVID-19 patients is represented by the dashed horizontal red lines (5 per 100,000 persons). Median values are represented by the black line. Each grey line represents one model realization out of 50 per scenario. Figures show the degree to which modifying R_0 by changing the transmission parameter (β) to 0.0303 (R_0=2.0), 0.0364 (R_0=2.4) and 0.0454 (R_0=3.0) from the fitted value of 0.0393 (R=2.7) has on projected ICU bed utilization.

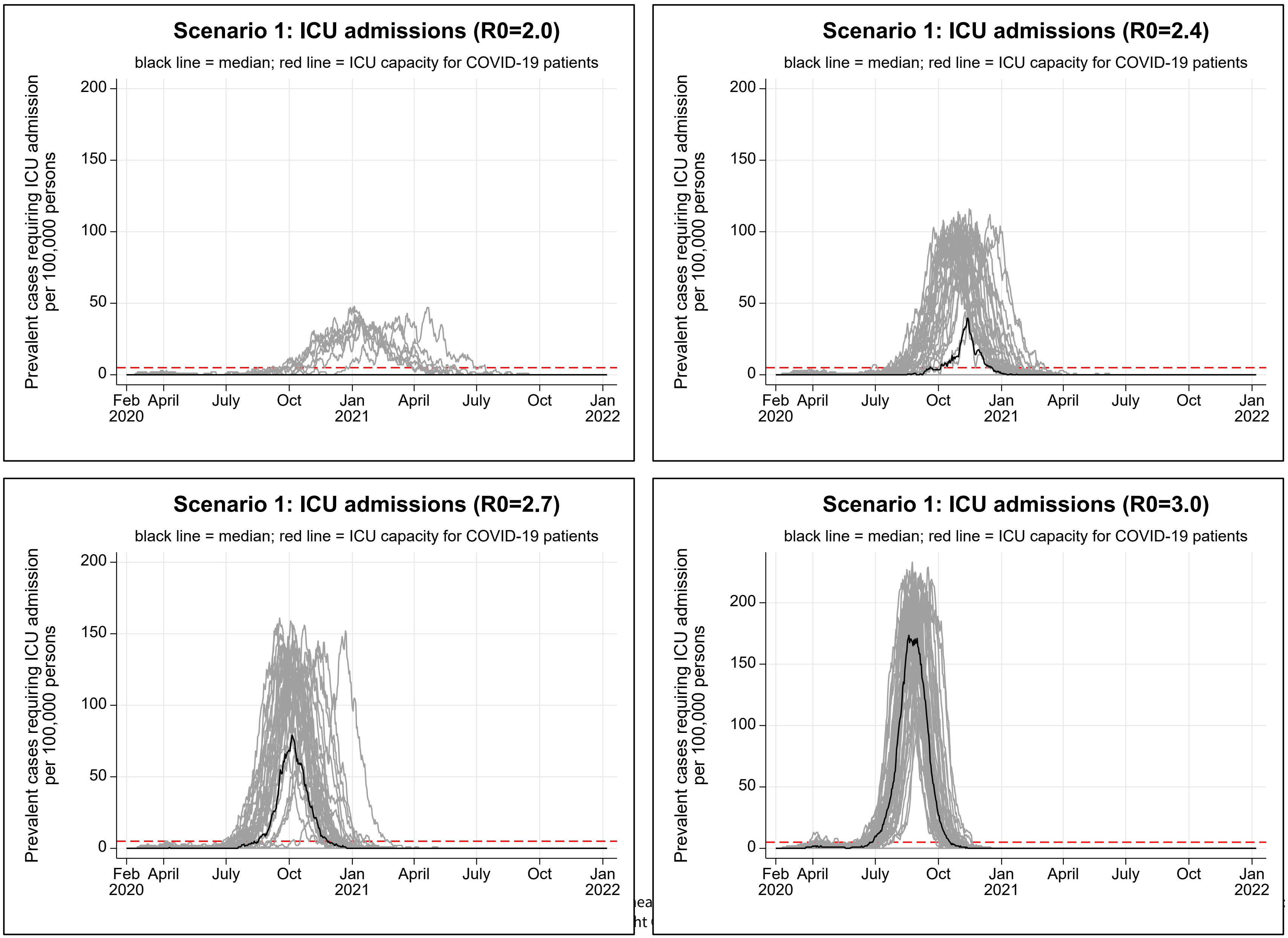


Figure S22. Projected ICU bed utilization showing daily ICU prevalence per 100,000 persons for Scenario 2 (maintained physical distancing) with comparison between four R_0 values. The maximum Canadian ICU bed capacity for COVID-19 patients is represented by the dashed horizontal red lines (5 per 100,000 persons). Median values are represented by the black line. Each grey line represents one model realization out of 50 per scenario. Figures show the degree to which modifying R_0 by changing the transmission parameter (β) to 0.0303 (R_0=2.0), 0.0364 (R_0=2.4) and 0.0454 (R_0=3.0) from the fitted value of 0.0393 (R=2.7) has on projected ICU bed utilization.

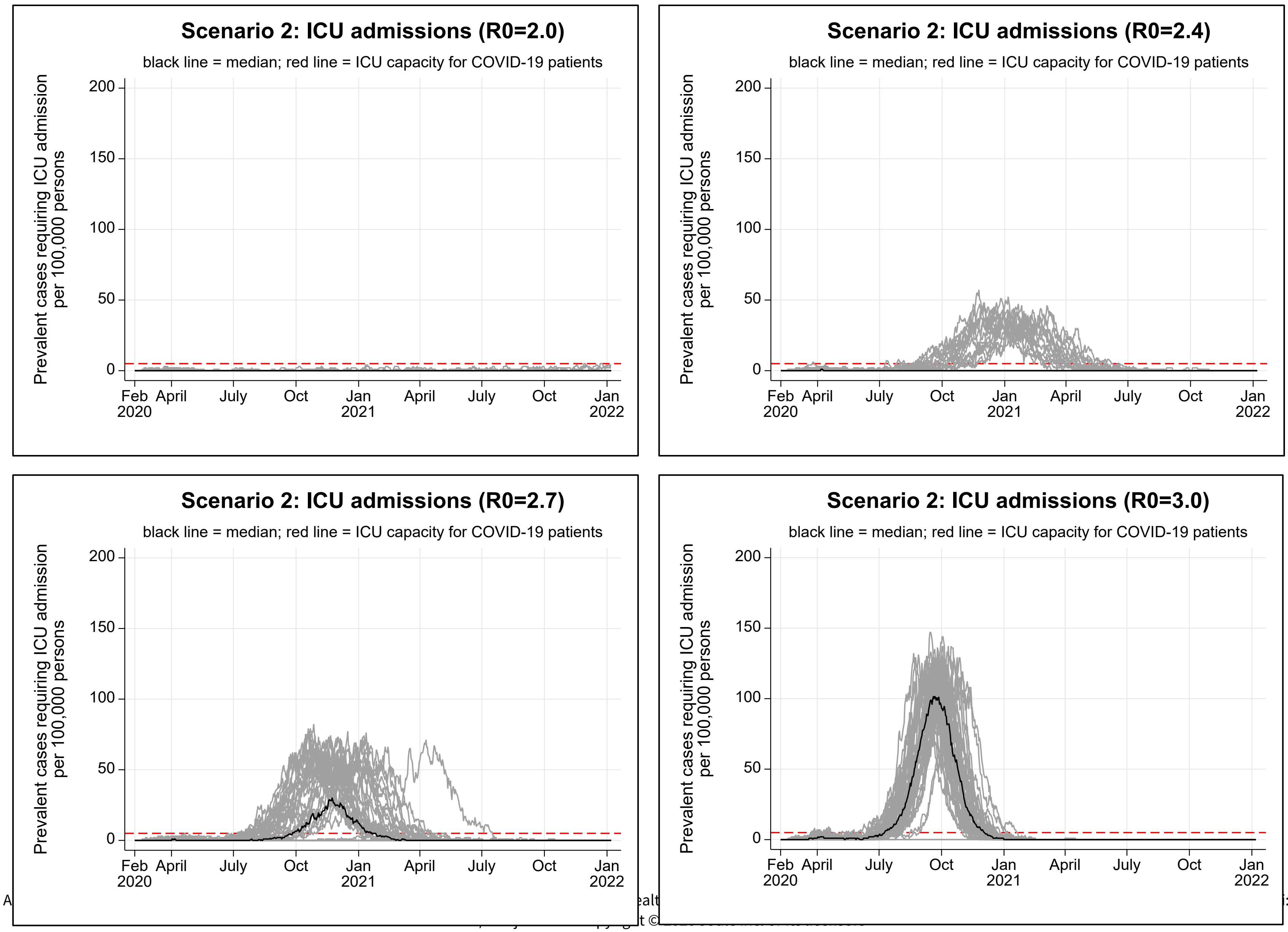


Figure S23. Projected ICU bed utilization showing daily ICU prevalence per 100,000 persons for Scenario 3 (enhanced case detection and contact tracing) with comparison between four R_0 values. The maximum Canadian ICU bed capacity for COVID-19 patients is represented by the dashed horizontal red lines (5 per 100,000 persons). Median values are represented by the black line. Each grey line represents one model realization out of 50 per scenario. Figures show the degree to which modifying R_0 by changing the transmission parameter (β) to 0.0303 (R_0=2.0), 0.0364 (R_0=2.4) and 0.0454 (R_0=3.0) from the fitted value of 0.0393 (R=2.7) has on projected ICU bed utilization.

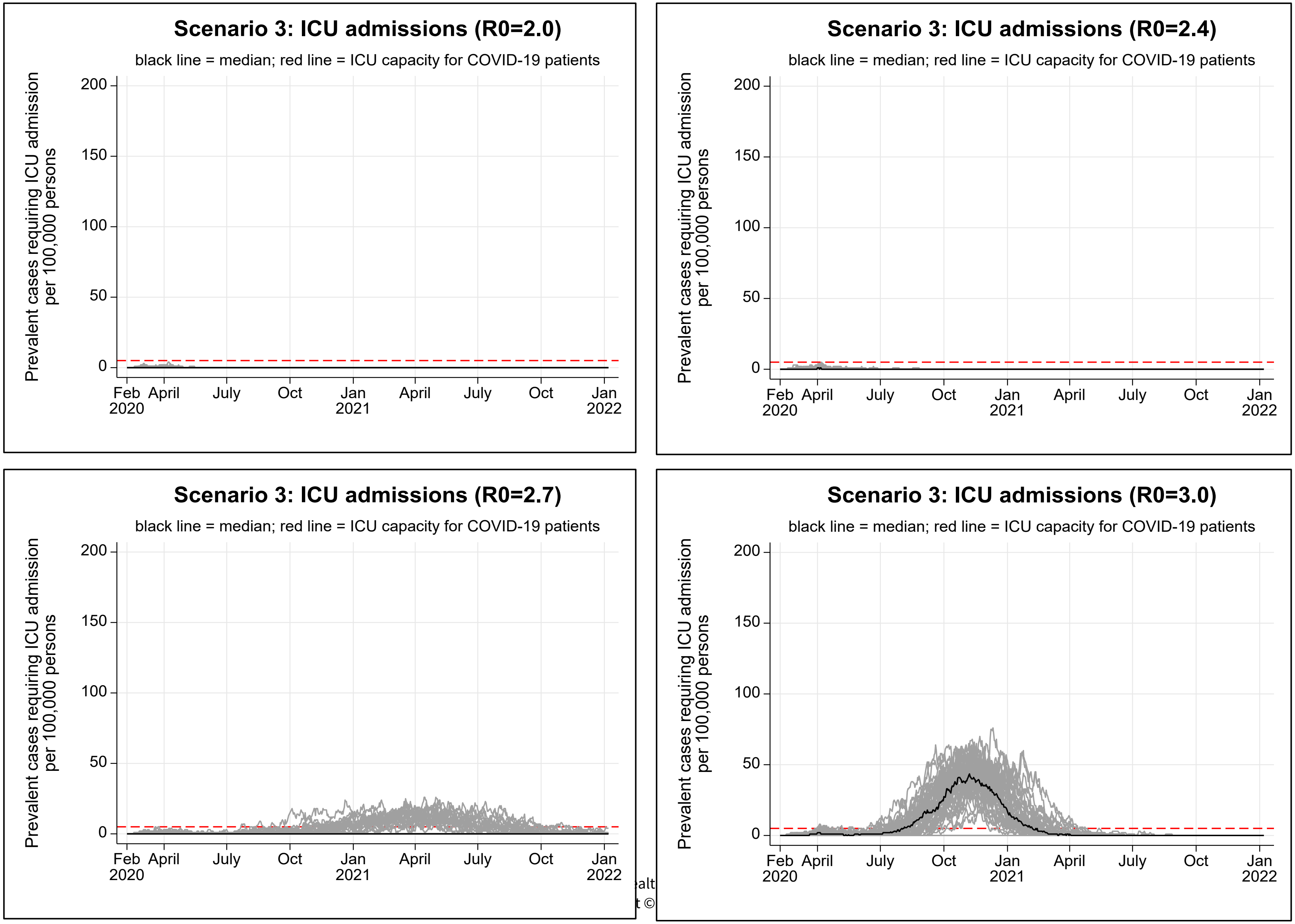
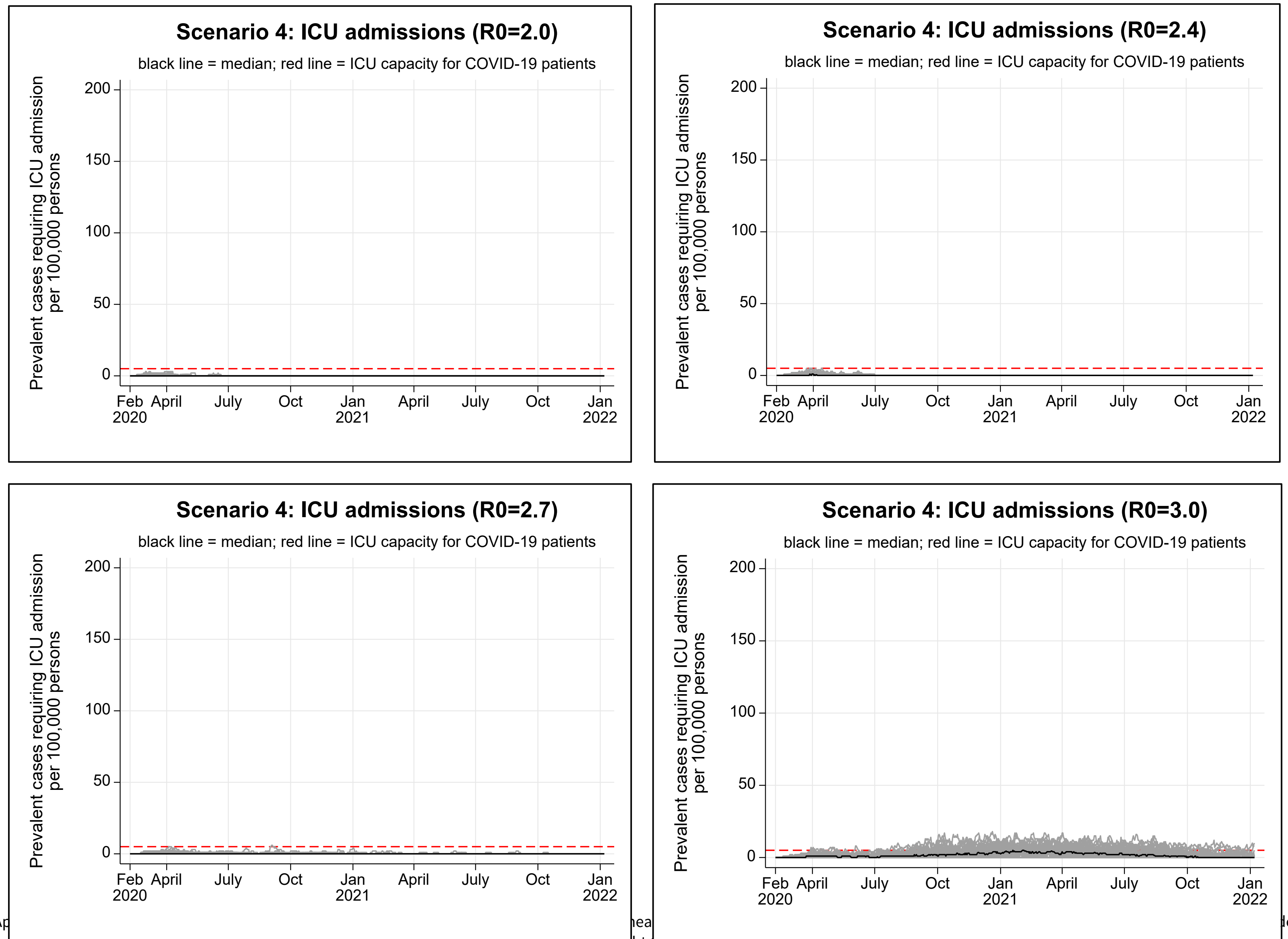


Figure S24. Projected ICU bed utilization showing daily ICU prevalence per 100,000 persons for Scenario 4 (combined interventions) with comparison between four R_0 values. The maximum Canadian ICU bed capacity for COVID-19 patients is represented by the dashed horizontal red lines (5 per 100,000 persons). Median values are represented by the black line. Each grey line represents one model realization out of 50 per scenario. Figures show the degree to which modifying R_0 by changing the transmission parameter (β) to 0.0303 (R_0=2.0), 0.0364 (R_0=2.4) and 0.0454 (R_0=3.0) from the fitted value of 0.0393 (R=2.7) has on projected ICU bed utilization.



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References

1. Public Health Agency of Canada (PHAC). Coronavirus Disease 2019 (COVID-19) Daily Epidemiological Update [Access date: June 10, 2020]. 2020. Available: https://health-infobase.canada.ca/covid-19/epidemiological-summary-covid-19-cases.html
2. Statistics Canada (StatsCan). Population estimates on July 1st, by age and sex 2020 [Available from: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1710000501.
3. Statistics Canada (StatsCan). Census Profile, 2016 Census 2016 [updated August 9, 2019. Available from: https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/details/page.cfm?Lang=E&Geo1=PR&Code1=35&Geo2=PR&Code2=01&Data=Count&SearchText=35&SearchType=Begins&SearchPR=01&B1=All&Custom=&TABID=3.
4. Prem K, Cook AR, Jit M. Projecting social contact matrices in 152 countries using contact surveys and demographic data. PLOS Computational Biology. 2017;13(9):e1005697.
5. Public Health Agency of Canada (PHAC). Canada COVID-19 Situation Awareness Dashboard [Assess date: June 27, 2020] 2020 [Available from: https://phac-aspc.maps.arcgis.com/apps/opsdashboard/index.html#/e968bf79f4694b5ab290205e05cfcda6.
6. Li R, Pei S, Chen B, Song Y, Zhang T, Yang W, Shaman J. Substantial undocumented infection facilitates the rapid dissemination of novel coronavirus (SARS-CoV-2). Science. 2020;368(6490):489-93.
7. Arons MM, Hatfield KM, Reddy SC, Kimball A, James A, Jacobs JR, Taylor J, Spicer K, Bardossy AC, Oakley LP, Tanwar S, Dyal JW, Harney J, Chisty Z, Bell JM, Methner M, Paul P, Carlson CM, McLaughlin HP, Thornburg N, Tong S, Tamin A, Tao Y, Uehara A, Harcourt J, Clark S, Brostrom-Smith C, Page LC, Kay M, Lewis J, Montgomery P, Stone ND, Clark TA, Honein MA, Duchin JS, Jernigan JA. Presymptomatic SARS-CoV-2 Infections and Transmission in a Skilled Nursing Facility. New England Journal of Medicine. 2020.
8. Grzelak L, Temmam S, Planchais C, Demeret C, Huon C, Guivel F, Staropoli I, Chazal M, Dufloo J, Planas D, Buchrieser J, Rajah MM, Robinot R, Porrot F, Albert M, Chen K-Y, Crescenzo B, Donati F, Anna F, Souque P, Gransagne M, Bellalou J, Nowakowski M, Backovic M, Bouadma l, Le Fevre L, Le Hingrat Q, Descamps D, Pourbaix A, Yazdanpanah Y, Tondeur L, Besombes C, Ungeheuer M-N, Mellon G, Morel P, Rolland S, Rey F, Behillil S, Enouf V, Lemaitre A, Creach M-A, Petres S, Escriou N, Charneau P, Fontanet A, Hoen B, Bruel T, Eloit M, Mouquet H, Schwartz O, van der Werf S. SARS-CoV-2 serological analysis of COVID-19 hospitalized patients, pauci-symptomatic individuals and blood donors. medRxiv. 2020:2020.04.21.20068858.
9. Gudbjartsson DF, Helgason A, Jonsson H, Magnusson OT, Melsted P, Norddahl GL, Saemundsdottir J, Sigurdsson A, Sulem P, Agustsdottir AB, Eiriksdottir B, Fridriksdottir R, Gardarsdottir EE, Georgsson G, Gretarsdottir OS, Gudmundsson KR, Gunnarsdottir TR, Gylfason A, Holm H, Jensson BO, Jonasdottir A, Jonsson F, Josefsdottir KS, Kristjansson T, Magnusdottir DN, le Roux L, Sigmundsdottir G, Sveinbjornsson G, Sveinsdottir KE, Sveinsdottir M, Thorarensen EA, Thorbjornsson B, Löve A, Masson G, Jonsdottir I, Möller AD, Gudnason T, Kristinsson KG, Thorsteinsdottir U, Stefansson K. Spread of SARS-CoV-2 in the Icelandic Population. New England Journal of Medicine. 2020.
10. Bloomberg News. New York finds virus marker in 13.9%, suggesting wide spread 2020 [Available from: https://www.bloomberg.com/news/articles/2020-04-23/new-york-finds-virus-marker-in-13-9-suggesting-wide-spread.
11. He W, Yi GY, Zhu Y. Estimation of the basic reproduction number, average incubation time, asymptomatic infection rate, and case fatality rate for COVID-19: Meta-analysis and sensitivity analysis. Journal of medical virology. 2020.
12. Davies NG, Klepac P, Liu Y, Prem K, Jit M, Eggo RM. Age-dependent effects in the transmission and control of COVID-19 epidemics. Nat Med. 2020.
13. Tong ZD, Tang A, Li KF, Li P, Wang HL, Yi JP, Zhang YL, Yan JB. Potential Presymptomatic Transmission of SARS-CoV-2, Zhejiang Province, China, 2020. Emerging infectious diseases. 2020;26(5):1052-4.

14. Xia W, Liao J, Li C, Li Y, Qian X, Sun X, Xu H, Mahai G, Zhao X, Shi L, Liu J, Yu L, Wang M, Wang Q, Namat A, Li Y, Qu J, Liu Q, Lin X, Cao S, Huan S, Xiao J, Ruan F, Wang H, Xu Q, Ding X, Fang X, Qiu F, Ma J, Zhang Y, Wang A, Xing Y, Xu S. Transmission of corona virus disease 2019 during the incubation period may lead to a quarantine loophole. medRxiv. 2020:2020.03.06.20031955.

15. Li C, Ji F, Wang L, Wang L, Hao J, Dai M, Liu Y, Pan X, Fu J, Li L, Yang G, Yang J, Yan X, Gu B. Asymptomatic and Human-to-Human Transmission of SARS-CoV-2 in a 2-Family Cluster, Xuzhou, China. Emerging infectious diseases. 2020;26(7).

16. Li G, Li W, He X, Cao Y. Asymptomatic and Presymptomatic Infectors: Hidden Sources of COVID-19 Disease. Clinical infectious diseases : an official publication of the Infectious Diseases Society of America. 2020.

17. Qian G, Yang N, Ma AHY, Wang L, Li G, Chen X, Chen X. A COVID-19 Transmission within a family cluster by presymptomatic infectors in China. Clinical infectious diseases : an official publication of the Infectious Diseases Society of America. 2020.

18. He X, Lau EHY, Wu P, Deng X, Wang J, Hao X, Lau YC, Wong JY, Guan Y, Tan X, Mo X, Chen Y, Liao B, Chen W, Hu F, Zhang Q, Zhong M, Wu Y, Zhao L, Zhang F, Cowling BJ, Li F, Leung GM. Temporal dynamics in viral shedding and transmissibility of COVID-19. Nature Medicine. 2020.

19. Tindale L, Coombe M, Stockdale JE, Garlock E, Lau WYV, Saraswat M, Lee Y-HB, Zhang L, Chen D, Wallinga J, Colijn C. Transmission interval estimates suggest pre-symptomatic spread of COVID-19. medRxiv. 2020:2020.03.03.20029983.

20. Hu Z, Song C, Xu C, Jin G, Chen Y, Xu X, Ma H, Chen W, Lin Y, Zheng Y, Wang J, Hu Z, Yi Y, Shen H. Clinical characteristics of 24 asymptomatic infections with COVID-19 screened among close contacts in Nanjing, China. Science China Life sciences. 2020;63(5):706-11.

21. Bi Q, Wu Y, Mei S, Ye C, Zou X, Zhang Z, Liu X, Wei L, Truelove SA, Zhang T, Gao W, Cheng C, Tang X, Wu X, Wu Y, Sun B, Huang S, Sun Y, Zhang J, Ma T, Lessler J, Feng T. Epidemiology and transmission of COVID-19 in 391 cases and 1286 of their close contacts in Shenzhen, China: a retrospective cohort study. The Lancet Infectious diseases. 2020.

22. Linton NM, Kobayashi T, Yang Y, Hayashi K, Akhmetzhanov AR, Jung SM, Yuan B, Kinoshita R, Nishiura H. Incubation Period and Other Epidemiological Characteristics of 2019 Novel Coronavirus Infections with Right Truncation: A Statistical Analysis of Publicly Available Case Data. Journal of clinical medicine. 2020;9(2).

23. Lauer SA, Grantz KH, Bi Q, Jones FK, Zheng Q, Meredith HR, Azman AS, Reich NG, Lessler J. The Incubation Period of Coronavirus Disease 2019 (COVID-19) From Publicly Reported Confirmed Cases: Estimation and Application. Annals of Internal Medicine. 2020.

24. Wang P, Lu J, Jin Y, Zhu M, Wang L, Chen S. Epidemiological characteristics of 1212 COVID-19 patients in Henan, China. medRxiv. 2020:2020.02.21.20026112.

25. Wang D, Hu B, Hu C, Zhu F, Liu X, Zhang J, Wang B, Xiang H, Cheng Z, Xiong Y, Zhao Y, Li Y, Wang X, Peng Z. Clinical Characteristics of 138 Hospitalized Patients With 2019 Novel Coronavirus–Infected Pneumonia in Wuhan, China. JAMA. 2020;323(11):1061-9.

26. Argenziano MG, Bruce SL, Slater CL, Tiao JR, Baldwin MR, Barr RG, Chang BP, Chau KH, Choi JJ, Gavin N, Goyal P, Mills AM, Patel AA, Romney M-LS, Safford MM, Schluger NW, Sengupta S, Sobieszczyk ME, Zucker JE, Asadourian PA, Bell FM, Boyd R, Cohen MF, Colquhoun MI, Colville LA, de Jonge JH, Dershowitz LB, Dey SA, Eiseman KA, Girvin ZP, Goni DT, Harb AA, Herzik N, Householder S, Karaaslan LE, Lee H, Lieberman E, Ling A, Lu R, Shou AY, Sisti AC, Snow ZE, Sperring CP, Xiong Y, Zhou HW, Natarajan K, Hripcsak G, Chen R. Characterization and Clinical Course of 1000 Patients with COVID-19 in New York: retrospective case series. medRxiv. 2020:2020.04.20.20072116.

27. Zhao W, Yu S, Zha X, Wang N, Pang Q, Li T, Li A. Clinical characteristics and durations of hospitalized patients with COVID-19 in Beijing: a retrospective cohort study. medRxiv. 2020:2020.03.13.20035436.

28. Guan W-j, Ni Z-y, Hu Y, Liang W-h, Ou C-q, He J-x, Liu L, Shan H, Lei C-l, Hui DSC, Du B, Li L-j, Zeng G, Yuen K-Y, Chen R-c, Tang C-l, Wang T, Chen P-y, Xiang J, Li S-y, Wang J-l, Liang Z-j, Peng Y-x, Wei L, Liu Y, Hu Y-h, Peng P, Wang J-m, Liu J-y, Chen Z, Li G, Zheng Z-j, Qiu S-q, Luo J, Ye C-j, Zhu S-y, Zhong N-s.

Clinical Characteristics of Coronavirus Disease 2019 in China. New England Journal of Medicine. 2020;382(18):1708-20.
29. Spiteri G, Fielding J, Diercke M, Campese C, Enouf V, Gaymard A, Bella A, Sognamiglio P, Sierra Moros MJ, Riutort AN, Demina YV, Mahieu R, Broas M, Bengnér M, Buda S, Schilling J, Filleul L, Lepoutre A, Saura C, Mailles A, Levy-Bruhl D, Coignard B, Bernard-Stoecklin S, Behillil S, van der Werf S, Valette M, Lina B, Riccardo F, Nicastri E, Casas I, Larrauri A, Salom Castell M, Pozo F, Maksyutov RA, Martin C, Van Ranst M, Bossuyt N, Siira L, Sane J, Tegmark-Wisell K, Palmérus M, Broberg EK, Beauté J, Jorgensen P, Bundle N, Pereyaslov D, Adlhoch C, Pukkila J, Pebody R, Olsen S, Ciancio BC. First cases of coronavirus disease 2019 (COVID-19) in the WHO European Region, 24 January to 21 February 2020. Eurosurveillance. 2020;25(9):2000178.
30. Bhatraju PK, Ghassemieh BJ, Nichols M, Kim R, Jerome KR, Nalla AK, Greninger AL, Pipavath S, Wurfel MM, Evans L, Kritek PA, West TE, Luks A, Gerbino A, Dale CR, Goldman JD, O'Mahony S, Mikacenic C. Covid-19 in Critically Ill Patients in the Seattle Region - Case Series. The New England journal of medicine. 2020.
31. Gold J, Wong K, Szablewski C, Patel P, Rossow J, da Silva J, Natarajan P, Morris S, Fanfair R, Rogers-Brown J, Bruce B, Browning S, Hernandez-Romieu A, Furukawa N, Kang M, Evans M, Oosmanally N, Tobin-D'Angelo M, Drenzek C, Murphy D, Hollberg J, Blum J, Jansen R, Wright D, Sewell III W, Owen J, Lefkove B, Brown F, Burton D, Uyeki T, Bialek, SR, Jackson B. Characteristics and Clinical Outcomes of Adult Patients Hospitalized with COVID-19 — Georgia, March 2020. MMWR Morbidity and mortality weekly report. 2020:545-50.
32. Yang X, Yu Y, Xu J, Shu H, Xia Ja, Liu H, Wu Y, Zhang L, Yu Z, Fang M, Yu T, Wang Y, Pan S, Zou X, Yuan S, Shang Y. Clinical course and outcomes of critically ill patients with SARS-CoV-2 pneumonia in Wuhan, China: a single-centered, retrospective, observational study. The Lancet Respiratory Medicine.
33. Zhang G, Hu C, Luo L, Fang F, Chen Y, Li J, Peng Z, Pan H. Clinical features and outcomes of 221 patients with COVID-19 in Wuhan, China. medRxiv. 2020:2020.03.02.20030452.
34. Zhou F, Yu T, Du R, Fan G, Liu Y, Liu Z, Xiang J, Wang Y, Song B, Gu X, Guan L, Wei Y, Li H, Wu X, Xu J, Tu S, Zhang Y, Chen H, Cao B. Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study. The Lancet. 2020;395(10229):1054-62.
35. Grasselli G, Zangrillo A, Zanella A, Antonelli M, Cabrini L, Castelli A, Cereda D, Coluccello A, Foti G, Fumagalli R, Iotti G, Latronico N, Lorini L, Merler S, Natalini G, Piatti A, Ranieri MV, Scandroglio AM, Storti E, Cecconi M, Pesenti A, Network ftC-LI. Baseline Characteristics and Outcomes of 1591 Patients Infected With SARS-CoV-2 Admitted to ICUs of the Lombardy Region, Italy. JAMA. 2020;323(16):1574-81.
36. Health Canada. Critical Care capacity summary internal report (April 10, 2020). In: Health Canada, editor. 2020.
37. Rajgor DD, Lee MH, Archuleta S, Bagdasarian N, Quek SC. The many estimates of the COVID-19 case fatality rate. The Lancet Infectious diseases. 2020.
38. Odone A, Delmonte D, Scognamiglio T, Signorelli C. COVID-19 deaths in Lombardy, Italy: data in context. The Lancet Public health. 2020.
39. Centre for Mathematical Modelling of Infectious Diseases (CMMID). Using a delay-adjusted case fatality ratio to estimate under-reporting 2020 [Available from: https://cmmid.github.io/topics/covid19/global_cfr_estimates.html.
40. Davies NG, Kucharski AJ, Eggo RM, Gimma A, Edmunds WJ, Jombart T, O'Reilly K, Endo A, Hellewell J, Nightingale ES, Quilty BJ, Jarvis CI, Russell TW, Klepac P, Bosse NI, Funk S, Abbott S, Medley GF, Gibbs H, Pearson CAB, Flasche S, Jit M, Clifford S, Prem K, Diamond C, Emery J, Deol AK, Procter SR, van Zandvoort K, Sun YF, Munday JD, Rosello A, Auzenbergs M, Knight G, Houben RMGJ, Liu Y. Effects of non-pharmaceutical interventions on COVID-19 cases, deaths, and demand for hospital services in the UK: a modelling study. The Lancet Public Health. 2020;5(7):e375-e85.
41. Google Canada. COVID-19 Community Mobility Report 2020 [Available from: https://www.gstatic.com/covid19/mobility/2020-05-09_CA_Mobility_Report_en.pdf.

42. Statistics Canada (StatsCan). Canadian Perspectives Survey Series 1: COVID-19 and working from home, 2020 2020 [Available from: https://www150.statcan.gc.ca/n1/daily-quotidien/200417/dq200417a-eng.pdf.

43. Statistics Canada (StatsCan). How are Canadians coping with the COVID-19 situation? 2020 [Available from: https://www150.statcan.gc.ca/n1/pub/11-627-m/11-627-m2020029-eng.htm.

44. Tang B, Scarabel F, Bragazzi N, McCarthy Z, Glazer M, Xiao Y, Heffernan J, Asgary A, Ogden N, Wu J. De-escalation by Reversing the Escalation with a Stronger Synergistic Package of Contact Tracing, Quarantine, Isolation and Personal protection: Feasibility of Preventing a COVID-19 Rebound in Ontario, Canada, as a Case Study. Biology. 2020;9(100).