Managing COVID-19 spread with voluntary public-health measures: Sweden as a case study for pandemic control

Shina C.L. Kamerlin[1,*] and Peter M. Kasson[2,3,*]

[1]Science for Life Laboratory, Department of Chemistry – BMC, Uppsala University, [2]Science for Life Laboratory, Dept. of Cell and Molecular Biology, Uppsala University, [3]Departments of Molecular Physiology and Biomedical Engineering, University of Virginia.

*Correspondence to lynn.kamerlin@kemi.uu.se or kassonlab@gmail.com

Box 800886, Charlottesville VA 22908 USA

Summary: Swedish COVID-19 public-health responses were analyzed using individual-based modeling. Voluntary self-isolation by a portion of the population explains reported COVID-19 mortality. ICU utilization is lower than anticipated and skewed by age, suggesting that additional care could medicinally benefit older adults.

Abstract

Background

The COVID-19 pandemic has spread globally, causing extensive illness and mortality. In advance of effective antiviral therapies, countries have applied different public-health strategies to control spread and manage healthcare need. Sweden has taken a unique approach of not implementing strict closures, instead urging personal responsibility. We analyze the results of this and other potential strategies for pandemic control in Sweden.

Methods

We implemented individual-based modeling of COVID-19 spread in Sweden using population, employment, and household data. Epidemiological parameters for COVID-19 were validated on a limited date range; where substantial uncertainties remained, multiple parameters were tested. The effects of different public-health strategies were tested over a 160-day period, analyzed for their effects on ICU demand and death rate, and compared to Swedish data for April 2020.

Results

Swedish mortality rates fall intermediate between European countries that quickly imposed stringent public-health controls and countries that acted later. Models most closely reproducing reported mortality data suggest large portions of the population voluntarily self-isolate. Swedish ICU utilization rates remained lower than predicted, but a large fraction of deaths occurred in non-ICU patients. This suggests that patient prognosis was considered in ICU admission, reducing healthcare load at a cost of decreased survival in patients not admitted.

Conclusions

The Swedish COVID-19 strategy has thus far yielded a striking result: mild mandates overlaid with voluntary measures can achieve results highly similar to late-onset stringent mandates. However, this policy causes more healthcare demand and mortality than early stringent control and depends on continued public will.

Keywords: COVID-19, individual-based modeling, public health mandates, individual behavior, healthcare capacity

Introduction

Since its emergence, SARS-CoV-2 has spread globally due to a lack of prior immunity combined with relatively high infectiousness [1-3]. This has caused substantial illness, mortality, and also strain on the healthcare systems of affected countries. Reported hospitalization rates are in the range of 12% [4] to 17% [5] of diagnosed cases, increasing with age. In severely affected regions, the availability of medically necessary care has become limiting. In advance of effective vaccines and therapies for COVID-19, countries have adopted different public health measures to reduce transmission. These have been classified as *suppressive* approaches, which aim to arrest transmission, and *mitigation* approaches, which aim to slow spread and shield vulnerable populations without truncating transmission [6, 7]. Sweden is perhaps the most prominent example of mitigation—limiting the extent of socially and economically disruptive interventions while still aiming to slow spread and allow for an effective medical response [7, 8]. Studying the effects of this strategy, which elements are key to reducing mortality and healthcare need, and how it might compare to other approaches is thus of critical importance to the global understanding of pandemic responses.

In addition to direct mortality, the potential of COVID-19 to saturate national healthcare systems is a key concern, as this affects both survival of COVID-19 patients and the ability to provide care for others in need. One critically limiting resource is the capacity of intensive care unit (ICU) beds with mechanical ventilation, since many COVID-19 patients die from causes related to respiratory failure [9, 10]. In global settings where ICU resources were not limiting, infection-fatality rates have been estimated in the range 0.36% to 1.2% [11-13]. Reported Swedish case-fatality rates were relatively high at 15% for April 2020 [14], although infection-fatality rates were certainly lower and much more difficult to determine reliably.

Numerical models of pandemic spread provide the ability to prospectively predict the effects of different public-health decisions [15] and help guide national policy [6, 7, 16-20]. In addition, they provide the critical ability to analyze, prospectively or retrospectively, which factors are key determinants of public-health outcome. The absolute predictions—numbers of deaths, precise hospital utilization—from such models include many uncertainties, but relative predictions have been highly informative. We classify predictive models into *aggregate* population models that yield basic principles of epidemic spread and *discrete* models that take into account geographic and demographic structure, permitting more specific assessment of different interventions. Discrete models offer a particular advantage here because the non-uniform structure of individual interactions alters infection spread, and differences in demography and social network structure are potential confounders when comparing pandemic behavior across countries.

In particular, individual-based models provide a flexible platform to analyze the propagation of emerging infectious diseases and the effect of social distancing and similar behavioral changes [21]. Because household, workplace, and community structure are explicitly represented in individual-based models, they provide a natural means to examine the effects of public-health strategies such as school and workplace closure or home-quarantine measures.

Because of Sweden's unique strategy of not imposing stringent public-health mandates, we used an individual-based model parameterized on Swedish demographics to assess the impact of measures deployed against COVID-19. Sweden's approach has advertised particular reliance on social distancing and voluntary individual behaviors supplementing public-health mandates, so we examined which of these measures is most likely to explain Swedish COVID-19 spread to date, what the future implications are for Sweden, and what lessons the global public health community can glean.

Methods

Individual-based model for pandemic spread

We used an individual agent-based model based on the framework published by Ferguson and co-workers [6, 22, 23] that we have re-implemented [24]. Details of the transmission model are given in [24] and briefly summarized here.

Geographic and demographic placement. Individuals were assigned location, age, and household randomly sampled from Swedish demographic data [25], capturing the small household size (2.2 per household, 39.8% single-occupancy [26]) that has been postulated as a reason for different COVID-19 transmission from the rest of Europe. Households were placed on a 30-arcsec lattice using LandScan population data [27] and initially assigned one adult over 20 years old. The remainder of the population for each lattice site was randomly distributed among households. In Sweden, only 5% of adults over 70 are in congregate living facilities [25]; these were not treated explicitly.

School and workplace assignment. Each individual was placed in a school or workplace. Individuals < 1 or > 75 years did not attend school or work. Schools were classified into three age levels and workplaces into two types. Following Swedish school-attendance data [28], 78% of children aged 1-3, 95% of children 3-5, and all children 6-15 were placed in schools in their city. Students 15-22 years old were assigned to secondary and tertiary schools in their county, using the mean Swedish school size of 220 [28].

Individuals were placed in workplaces of 15 people each following Swedish employment rates: 77.3% for ages 22-65 and 17.2% for ages 65-75 [25]. Approximately 95% of Swedish workplaces have 1-9 employees [25]; the 15-person size was chosen to incorporate inter-workplace interactions and the skewing effect of larger workplaces. Hospitals were treated as separate workplaces with 120 employees on average and at least one per county, consisting of 4.3% of the total workforce [26]. Hospital workers were considered occupationally exposed to each other as well as patients, but at 25% the exposure risk of other workplaces to account for infection-control precautions (see Supplement for discussion of Swedish precautions).

Initial infections. Initial infections were randomly seeded to match the per-county case distribution reported as of March 25th, 2020 (date of Sweden's 100th death) [14]. To correct for under-testing bias, the number of initial infections was estimated from COVID-19 intensive-care unit (ICU) admissions from March 17th to 31st, using prior estimates that 2.95% of infections overall result in hospitalization and 30% of those in ICU admission [6].

Transmission dynamics. Disease transmission was modelled via discrete-time stochastic simulation on an individual basis; further details are given in the Supplement and our prior work [24]. Briefly, transmission can occur in workplaces or schools, households, and communities. An individual's probability of becoming infected is the sum of these exposures.

Transmissibility factors. Individual-based models have been used for a number of emerging diseases; one key disease-specific parameter is the transmissibility within the studied population (analogous to the beta parameter in compartmental SEIR models [29]). Twenty values of this parameter were tested and selected for best agreement with either aggregate growth in cases across Europe [30] or growth in reported Swedish deaths [14] from March 21 to April 6. The resulting transmissibility factors correspond to doubling rates of 3 days (shown in the Supplement) and 5 days (main text results), respectively.

Statistical sampling. Ten independent runs were performed per parameter set; the 90% confidence intervals for measured outcomes across these runs were relatively tight, indicating that uncertainties in biological parameters rather than statistical sampling is most limiting on overall error. For death estimates, 95% confidence intervals for age-adjusted infection fatality rates in China [11] were calculated and propagated through the model (Fig. S1).

Public-health interventions

Several public-health interventions were simulated, including both universal mandates and voluntary individual behaviors. The mandates considered were chosen to approximate public-health options considered or adopted elsewhere. Transmission scaling factors in each of the mandate-based interventions below are based on previous work [6] and also follow our initial implementation [24].

1) *Swedish public health mandates*. This models Swedish government mandates (not including voluntary behavior) through April 2020. Students aged 15-22 years old did not attend school, removing school transmission and increasing community transmission by 25% and household transmission by 50%. Persons aged over 70 practiced moderate self-isolation, reducing workplace and community transmission by 75%. Symptomatic individuals self-isolated after 1 day with a 90% compliance rate, abrogating workplace transmission and reducing community transmission by 75%. Additional interventions considered below were implemented as additions to these mandates.

2) *Case isolation of entire households*. Everyone sharing a household with a symptomatic person was advised to self-quarantine. For these individuals, community transmission was reduced by 75%, workplace transmission removed, and household transmission increased by 50%. Compliance was estimated at 70% for asymptomatic and 90% for symptomatic individuals.

3) *School closure*. All schools were closed. Students had no school transmission but 50% increased household and 25% community transmission.

4) *Simple closure of schools and non-essential businesses*. Schools and non-essential businesses were closed, but social distancing was not advised. School transmission was removed, workplace transmission reduced by 75%, household transmission increased by 75%, and community transmission increased by 50%.

5) *Closure of schools and non-essential businesses with social distancing*. As per intervention 4, but with social distancing. School transmission was removed, workplace transmission reduced by 75%, household transmission increased by 50%, and community transmission decreased by 75%. This was practiced with 90% compliance.

6) *Voluntary work-from-home*. A specified fraction of individuals worked from home; their community transmission was decreased by 25% and household transmission increased by 50%.

7) *Voluntary self-isolation*. A specified fraction of individuals self-isolated; their workplace transmission was removed, community transmission decreased 75%, and household transmission increased 100%.

8) *Voluntary work-from-home overlaid on mild social distancing*. As per intervention 6 but all other individuals reduced community transmission by 25%.

9) *Voluntary self-isolation overlaid on mild social distancing*. As per intervention 7 but all other individuals reduced community transmission by 25%.

Healthcare capacity

Swedish pre-pandemic healthcare capacity was assessed based on the most recent pan-European reports available: 5.8 intensive care beds per 100,000 inhabitants [31].

Implementation

Code implementing the model and interventions tested is freely available on https://github.com/kassonlab/covid19-epi. Data files are available on Zenodo (DOI: 10.5281/zenodo.3836195).

Results

Models of COVID-19 spread were initialized with data for the period until March 21, validated against reported death rates for the period March 21 to April 6, and evaluated against death data from April 6 onwards. Because RT-PCR testing was not performed on a widespread basis in Sweden, we estimated initial infections in the period until March 21 *via* back-calculation from ICU admissions.

Numbers of infected individuals, hospitalization need, ICU admission need, and deaths were estimated using either a mandate-only strategy or a voluntary-isolation strategy across a range of epidemiological parameters. These were evaluated against reported COVID-19 deaths in Sweden over the period from April 6 to 30. The resulting mortality estimates (Fig. 1, infected individuals in Fig. S2) show that voluntary isolation can have a substantial effect on COVID mortality. Models of the Swedish public-health mandates alone predict substantially more deaths in April than were reported, while self-isolation by a moderate fraction of the population can well reproduce the reported death toll. While redundancies in the model parameter space and uncertainty regarding delayed death registrations preclude assignment of a unique set of "best fit" parameters, the agreement with reported death tolls demonstrates that the model is able to capture Swedish mortality data with epidemiological parameters within the range of international best estimates.

Perhaps most importantly, this analysis suggests that approximately 30% of Swedish residents have self-isolated in some form. Mobile-phone location data can provide rough estimates of this quantity. While detailed interpretation of these data is a complex undertaking, reports from Google and others [32, 33] suggest a decrease in workplace presence of between 18% and 33% during the month of April. Our analysis is consistent with these numbers. As with any voluntary measures, adoption varied both over the course of April and in different regions of the country; those variations are not treated explicitly here. Furthermore, because diagnosed cases and deaths are lagging indicators of infection, individual modulation of voluntary measures is unlikely to result in optimal choice of control measures. For instance, premature relaxation of voluntary measures may contribute to further spread.

We also evaluated alternative public-health mandates. Each of these was considered from March 21 onward, and the relative impact estimated on mortality, ICU demand, and individuals infected (Figs. 2 and S3). In agreement with prior predictions [34, 35], these results suggest that strong public-health mandates greatly reduce mortality and healthcare need. Surprisingly, voluntary self-isolation overlaid on the existing public-health mandates achieved results within 9-fold of strong mandates at a voluntary adherence rate of 30%, within 7-fold if mild social distancing were overlaid, and within 5-fold at an adherence rate of 50% with mild social distancing. This suggests that voluntary control efforts, if widely implemented, can have a substantial effect on transmission. Working from home reduced mortality and ICU demand substantially, but the decreased community transmission resulting from self-isolation had a substantial additional effect at all adherence rates. For all public-health interventions considered, prompt implementation is critical to success. The predicted effects of variable delays in voluntary adherence are plotted in Fig. 3, showing a substantial loss of effectiveness with increasing delay.

Model predictions suggest that the Swedish public-health mandates alone would have resulted in approximately 40-fold more patients (median 42, 90% CI 42-43; statistical sampling not limiting on error) who could benefit from ICU care than ICU beds available pre-pandemic (Fig. 4). Voluntary self-isolation of 50% of the population reduced this to 5-fold (90% CI 4.8-5.1), and strong suppressive mandates would have reduced it to 1.5-fold (90% CI 1.4-1.5). As part of its public-health response, Sweden approximately doubled its number of ICU beds during spring 2020. However, not all ICU beds were occupied—the number of unique patients receiving COVID ICU care was approximately 53% of the total COVID-diagnosed deaths at the start of May 2020 [14, 36] To analyze this, we examined the demographic characteristics of patients diagnosed with COVID-19, patients admitted to the ICU, and patients who died with a confirmed COVID-19 diagnosis [25]. Analyzed by categorical age group, older Swedish patients with confirmed COVID-19 were more likely to die than to be admitted to the ICU (Fig. 5), suggesting that predicted prognosis may have been a factor in ICU admission. This likely reduced ICU load at the cost of more high-risk patients dying outside the ICU.

Discussion

Sweden has attracted much international attention for its different approach to the COVID-19 pandemic. By applying only very light mandates—closure of high schools and universities only and advising isolation by symptomatic individuals and those over 70—it appears a substantial outlier in its public health strategy. Our analysis suggests that individual actions in Sweden have created a more graduated scenario: voluntary self-isolation in Sweden has provided a combined population response *intermediate* between the public-health mandates alone and the stronger mandate regime implemented by other countries and regions. Sweden has had a similarly intermediate number of reported COVID-19 deaths—fewer per capita than Italy, Spain, and the United Kingdom but more than its Scandinavian neighbors that implemented strong measures promptly and more than most other European countries (Supplementary Table 1; 35/100,000 in Sweden versus 9.3 in Denmark, 5.2 in Finland, and 4.7 in Norway as of May 15). Benefits of the individual-response approach include increased flexibility; drawbacks include decreased coordination in the maintenance and strategic relaxation of controls. Predicted deaths and ICU demand are also greater with voluntary adherence than with stringent mandates until adherence rates exceed 75%. Whether mandated or voluntary, self-isolation of a substantial fraction of the population profoundly reduces ICU need and mortality if applied early and with substantial adherence rates. It therefore also follows that greater self-isolation in Sweden would have commensurately reduced deaths. Most national strategies consider both public-health and economic effects of infection-control mandates; based on preliminary European data, the economic impacts on Sweden appear similar to its neighbors [37].

Our analysis yields qualitatively similar results to those obtained using other model formalisms [8, 34]; one advantage of an individual-based model is explicit representation of demographic data, so differences between countries can be analyzed based purely on data rather than parameterized. In addition, individual-based models facilitate examination of non-uniform behaviors across a population: self-isolation by 50% of the population all the time has markedly different effects than self-isolation by all of the population 50% of the time. Different models have yielded convergent predictions that individual action can increase the efficacy of public-health measures, but high adoption is necessary for disease suppression and both rapid and sustained action are required. This suggests that the underlying findings are indeed robust.

Our analyses demonstrate how individual-based modeling can account for both the unmitigated spread of COVID-19 pandemic and its control via either suppressive measures or substantial voluntary self-isolation. We demonstrate that Sweden is likely not exceptional in its demography or other parameters controlling the epidemic spread of COVID-19; instead, the course of the pandemic in Sweden likely results from the overlay of public-health mandates and individual control measures. We further note that control of ICU load during the pandemic may reflect ICU admission criteria applied. Substantial uncertainty remains regarding the key biological variables controlling COVID-19 spread as well as human behavioral changes, and models of this nature are not designed to predict the future precisely. Our analyses nonetheless suggest that voluntary control strategies are highly dependent on continued individual adherence, which may prove difficult over time.

NOTES

Acknowledgements

The authors thank Åke Sandgren and Lars Viklund for code optimization and Milad Sharifpour, Nele Brusselaers, and Wouter van der Wijngaart for helpful discussions.

Funding sources

This work was supported by the Knut and Alice Wallenberg Foundation [grant numbers 2015.0198 to P.K., 2018.0140 to S.C.L.K., and 2019.0431 to S.C.L.K.]. Computational resources were from the Swedish National Infrastructure for Computing [grant number SNIC 2020/5-176] at High Performance Computing Center North, Uppsala Multidisciplinary Center for Advanced Computational Science, National Supercomputer Center Sweden, and PDC Center for High Performance Computing.

Potential conflicts of interest

The authors report no potential conflicts of interest. All authors have submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest. Conflicts that the editors consider relevant to the content of the manuscript have been disclosed.

References

1. Li Q, Med M, Guan X, et al. Early Transmission Dynamics in Wuhan, China, of Novel Coronavirus–Infected Pneumonia. N Engl J Med **2020**; 382: 1199-207.
2. Wölfel R, Corman VM, Guggemos W, et al. Virological Assessment of Hospiatlized Patients with COVID-19. Nature **2020**: DOI: 10.1038/s41586-020-2196-x.
3. Zhou P, Yang X-L, Wang X-G, et al. A Pneumonia Outbreak Associated with a New Coronavirus of Probable Bat Origin. Nature **2020**; 579: 270-3.
4. CDC Covid-Response Team. Severe outcomes among patients with coronavirus disease 2019 (COVID-19). Morb Mortal Wkly Rep (MMRW) **2020**; 69: 343-6.
5. Täglicher Lagebericht des RKI zur Coronavirus-Krankheit-2019 (COVID-19): Robert Koch Institute, **2020** May 12, 2020.
6. Ferguson NM, Laydon D, Nedjati-Gilani G, et al. Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand. **2020**: DOI: 10.25561/77482.
7. Walker PGT, Whittaker C, Watson O, et al. The global impact of COVID-19 and strategies for mitigation and suppression. **2020**: DOI: 10.25561/77735.
8. Flaxman S, Mishra S, Gandy A, et al. Estimating the effects of non-pharmaceutical interventions on COVID-19 in Europe. Nature **2020**.
9. Guan WJ, Ni ZY, Hu Y, et al. Clinical Characteristics of Coronavirus Disease 2019 in China. N Engl J Med **2020**; In Press DOI: 10.1056/NEJMoa2002032.
10. Chen N, Zhou M, Dong X, et al. Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study. Lancet **2020**; 395: 507-13.
11. Verity R, Okell LC, Dorigatti I, et al. Estimates of the severity of COVID-19 disease: a model-based analysis. Lancet Infect Dis **2020**; Online First: DOI: 10.1016/S473-3099(20)30243-7.
12. Russell TW, Hellewell J, Jarvis CI, et al. Estimating the infection and case fatality ratio for coronavirus disease (COVID-19) using age-adjusted data from the outbreak on the Diamond Princess cruise ship, February 2020. Euro Surveill **2020**; 25(12).
13. Streeck H, Schulte B, Kuemmerer B, et al. Infection fatality rate of SARS-CoV-2 infection in a German community with a super-spreading event. medRxiv **2020**.
14. Public Health Agency of Sweden (Folkhälsomyndigheten) Available at: https://www.folkhalsomyndigheten.se/. Accessed 12 May 2020.
15. Adam D. Special report: The simulations driving the world's response to COVID-19: How epidemiologists rushed to model the coronavirus pandemic. . Nature **2020**; 580: 316-8.
16. Fan C, Liu L, Guo W, et al. Prediction of epidemic spread of the 2019 novel coronavirus driven by spring festival transportation in China: A population-based study. Int J Environ Res Public Health **2020**; 17: DOI: 10.3390/ijerph17051679.
17. Zhang S, Diao M, Yu W, Pei L, Lin Z, Chen D. Estimation of the reproductive number of novel coronavirus (COVID-19) and the probable outbreak size on

the Diamond Princess cruise ship: A data-driven analysis. Int J Infect Dis **2020**; 93: 201-4.
18. Petropoulos F, Makridakis S. Forecasting the novel coronavirus COVID-19. PLoS One **2020**; 15: e0231236.
19. Wang H, Wang Z, Dong Y, et al. Phase-adjusted estimation of the number of Coronavirus Disease 2019 cases in Wuhan, China. Cell Discov **2020**; 6: 10.
20. Kissler SM, Tedijanto C, Goldstein E, Grad YH, Lipsitch M. Projecting the transmission dynamics of SARS-CoV-2 through the postpandemic period. Science **2020**.
21. Willem L, Verelst F, Bilcke J, Hens N, Beutels P. Lessons from a decade of individual-based models for infectious disease transmission: a systematic review (2006-2015). BMC Infect Dis **2017**; 17: 612.
22. Ferguson NM, Cummings DA, Cauchemez S, et al. Strategies for containing an emerging influenza pandemic in Southeast Asia. Nature **2005**; 437: 209-14.
23. Ferguson NM, Cummings DA, Fraser C, Cajka JC, Cooley PC, Burke DS. Strategies for mitigating an influenza pandemic. Nature **2006**; 442: 448-52.
24. Gardner JM, Willem L, van der Wijngaart W, Kamerlin SCL, Brusselaers N, Kasson P. Intervention strategies against COVID-19 and their estimated impact on Swedish healthcare capacity. medRxiv **2020**.
25. Statistics Sweden (SCB): Population statistics. Available at: http://www.statistikdatabasen.scb.se/pxweb/sv/ssd/. Accessed 12 May 2020.
26. OECD. Organisation for Economic Cooperation and Development (OECD) iLibrary.
27. Landscan TM Global: Geographic Information Science & Technology. Available at: https://landscan.ornl.gov/. Accessed 27 March, 2020.
28. The Swedish National Agency for Education (Skolverket). Available at: https://www.skolverket.se/. Accessed 11 April 2020.
29. Xu R, Ma Z. Global stability of a SIR epidemic model with nonlinear incidence rate and time delay. Nonlinear Anal-Real **2009**; 10(5): 3175-89.
30. Pellis L, Scarabel F, Stage HB, et al. Challenges in control of Covid-19: short doubling time and long delay to effect of interventions. arXiv:2004.00117
31. Rhodes A, Ferdinande P, Flaatten H, et al. The variability of critical care bed numbers in Europe. Intensive Care Med **2012**; 38: 1647-53.
32. Mobility Trends Reports. In: Apple I, **2020**.
33. COVID-19 Community Mobility Reports. In: Google I, **2020**.
34. Sjödin H, Johansson AF, Farooq Z, et al. Covid-19 health care demand and mortality in Sweden in response to nonpharmaceutical (NPIs) mitigation and suppression scenarios. medRxiv **2020**: DOI: 10.1101/2020.03.20.20039594.
35. Wu JT, Leung K, Bushman M, et al. Estimating clinical severity of COVID-19 from the transmission dynamics in Wuhan, China. Nat Med **2020**; 26(4): 506-10.
36. The Swedish Intensive Care Registry. Available at: https://www.icuregswe.org/data--resultat/covid-19-i-svensk-intensivvard/. Accessed 12 May 2020.
37. European Economic Forecast Spring 2020. Luxembourg: European Commission, **2020** May 2020.

Legends:

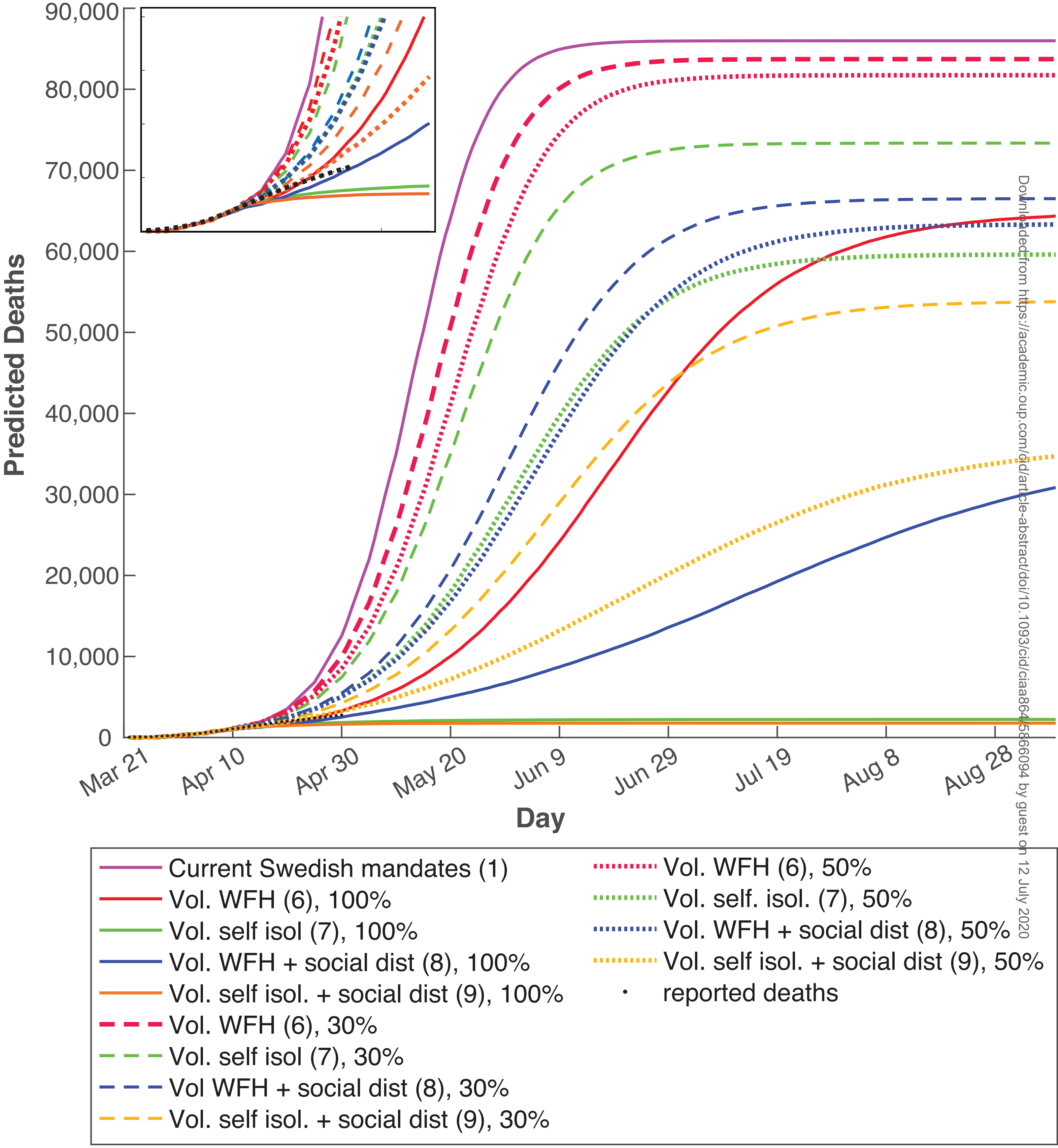
Figure 1. Predicted COVID-19 deaths in Sweden with different voluntary-adherence strategies. Plotted are median number of COVID-19 deaths predicted by modeling current Swedish public-health mandates and individual voluntary behaviors. These are compared against reported COVID-19 deaths in Sweden. A moderate level of individual self-isolation is sufficient to well reproduce the reported death tolls. Data are shown for 3-day doubling times (see Figs. S4-S5 for alternates). Numbers in parentheses match interventions in the Methods. WFH denotes work from home. April predictions are enlarged in the inset.

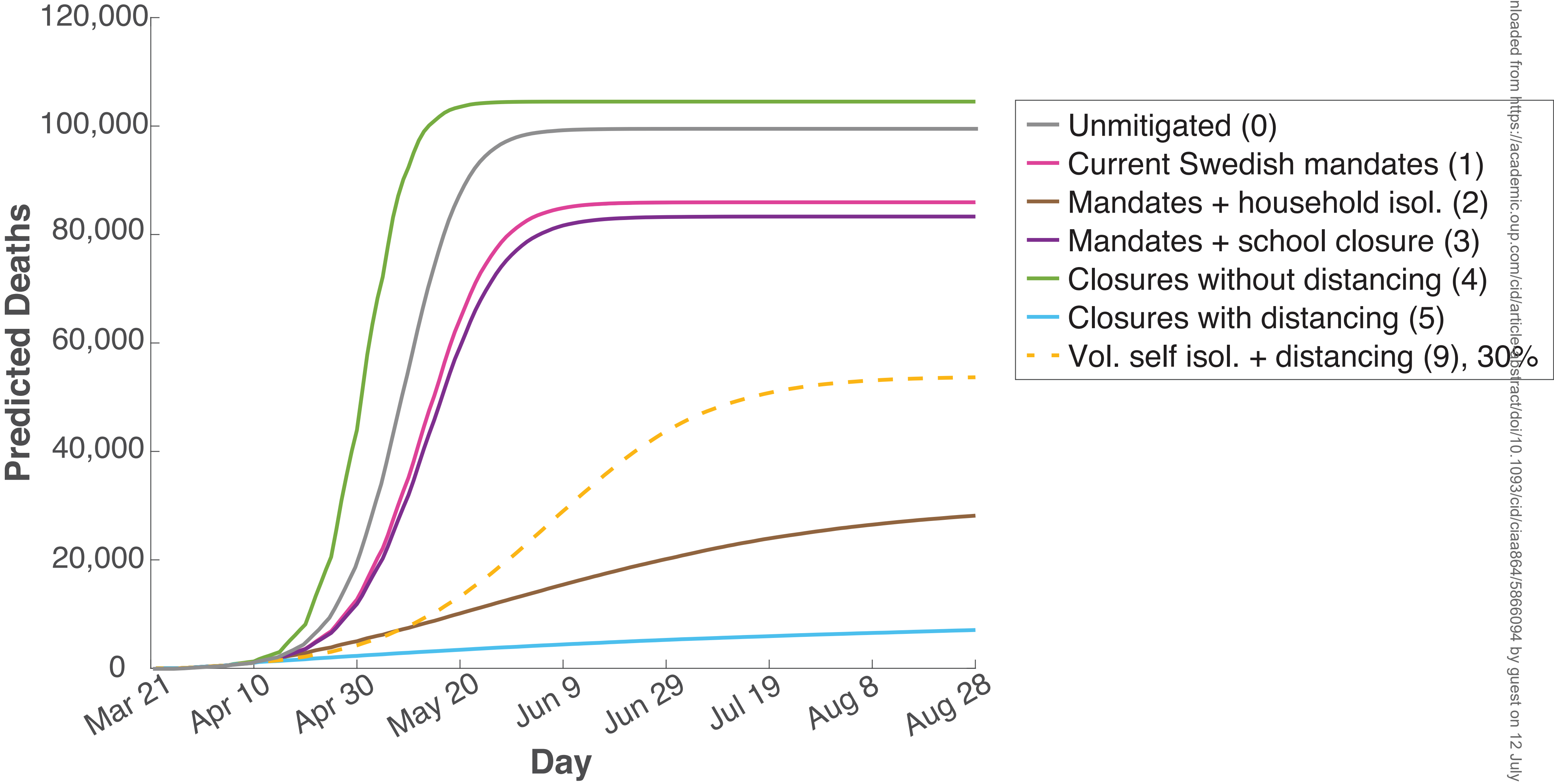
Figure 2. Predicted COVID-19 deaths in Sweden with different public-health mandates. Plotted are median number of COVID-19 deaths predicted by modeling current Swedish public-health mandates and alternate strategies. A single voluntary behavior is plotted as a comparator. Numbers in parentheses match interventions in the Methods.

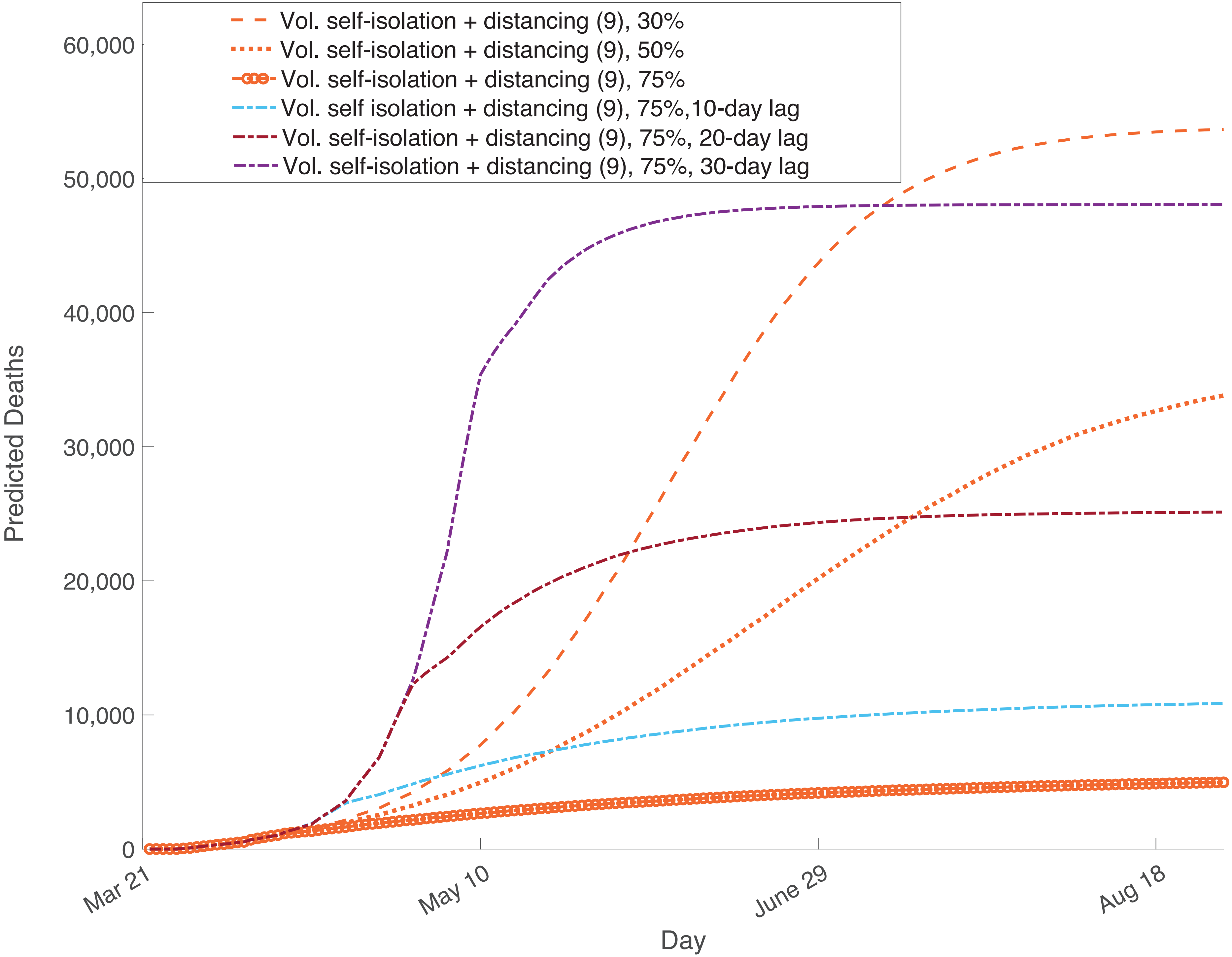
Figure 3. Effects of delayed implementation on mortality. Predicted numbers of deaths are plotted for the strongest set of interventions considered at varying voluntary ratios and time lags before implementation. Infection could still be suppressed effectively with a 10-day delay, but a 30-day delay greatly increased predicted death toll.

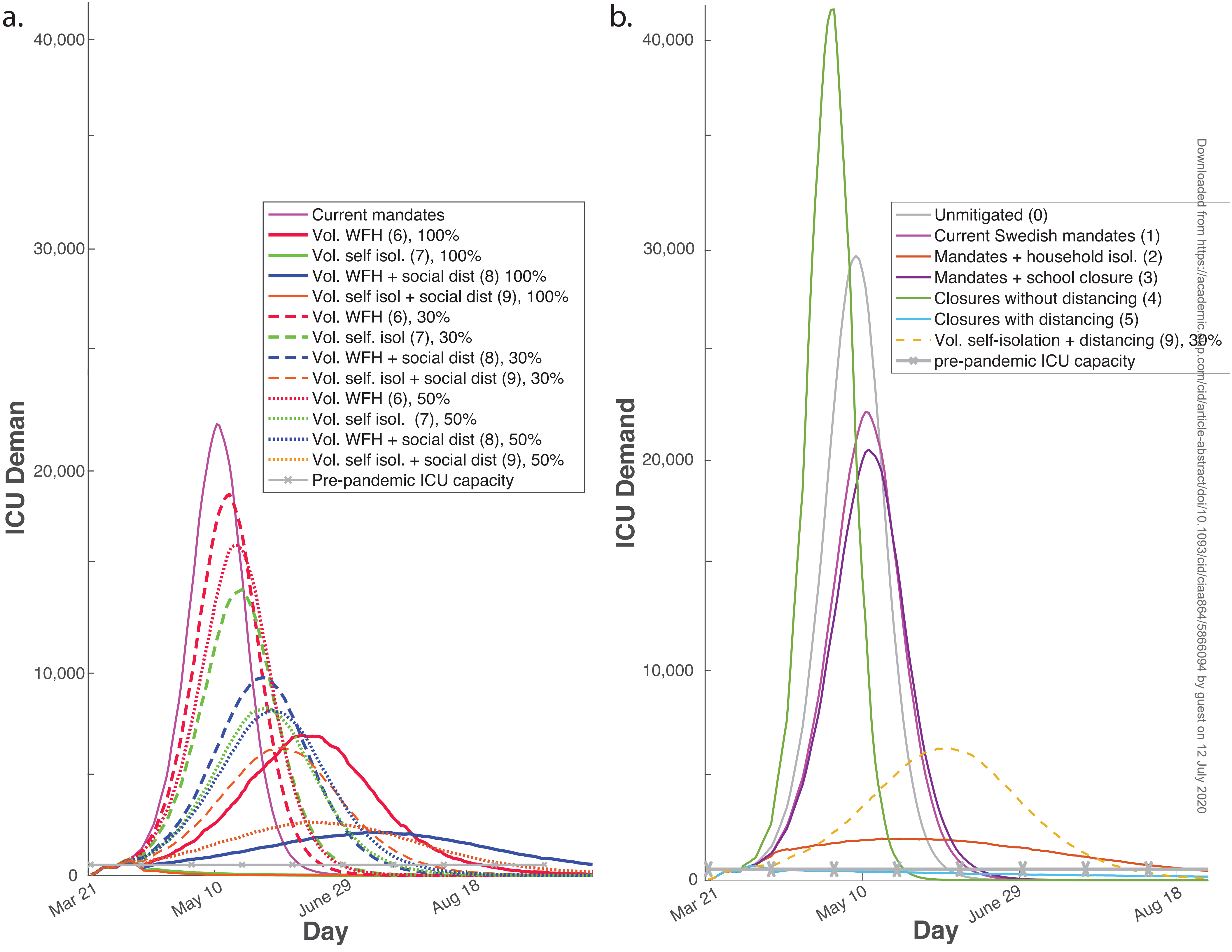
Figure 4. Predicted ICU demand with different mandate and voluntary strategies. ICU demand predicted by modeling selected public-health mandates and voluntary behaviors is plotted in panel (a), with Swedish pre-pandemic and pandemic surge capacities shown in dotted lines. Plotted in panel (b) is the median number of individuals predicted to require intensive care at the indicated date for each of the indicated public-health mandates, again compared to the reported Swedish pre-pandemic ICU capacity.

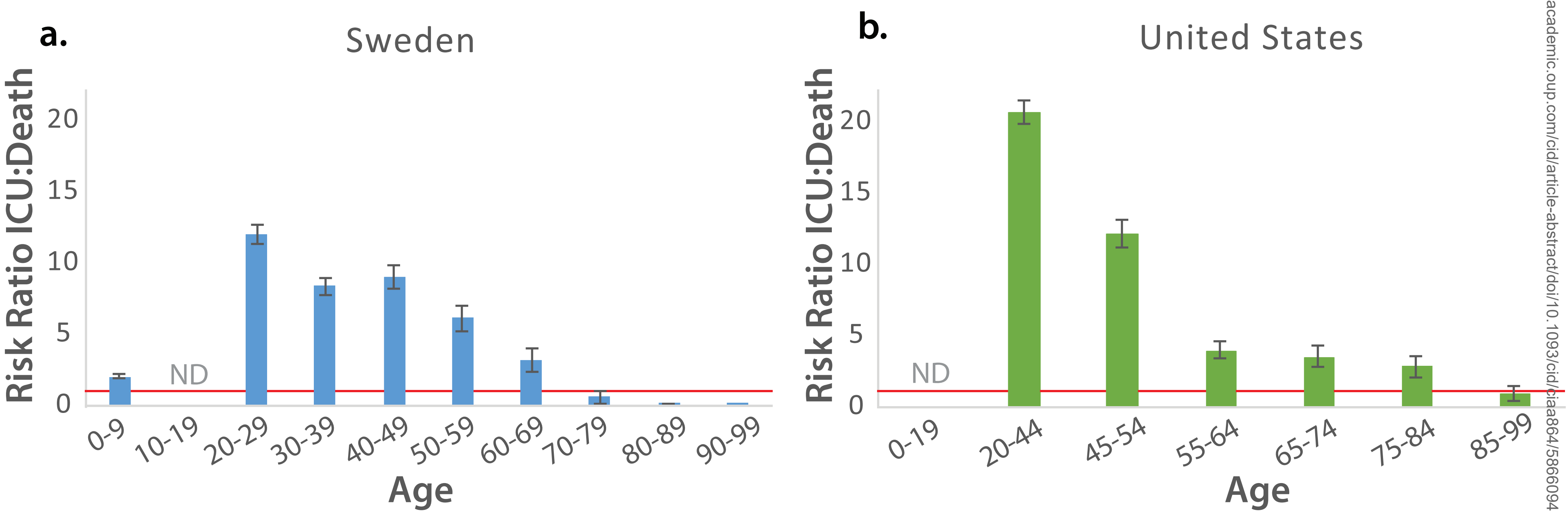
Figure 5. Risk of ICU admission versus death due to COVID-19. The risk of ICU admission due to COVID-19 versus death due to COVID-19 are plotted for reported cases for categorical age ranges in (a) Sweden and (b) the United States. Age categorization is plotted according to original data sources. A red line shows risk ratio of 1; ND denotes no reported deaths. Swedish data show substantially higher likelihood of death than of ICU admission for patients aged over 70 years (ratio below 1.0). Error bars represent standard error.


Predicted Deaths
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Mar 21
Apr 10
Apr 30
May 20
Jun 9
Jun 29
Jul 19
Aug 8
Aug 28
Day
Current Swedish mandates (1)
Vol. WFH (6), 100%
Vol. self isol (7), 100%
Vol. WFH + social dist (8), 100%
Vol. self isol. + social dist (9), 100%
Vol. WFH (6), 30%
Vol. self isol (7), 30%
Vol WFH + social dist (8), 30%
Vol. self isol. + social dist (9), 30%
Vol. WFH (6), 50%
Vol. self. isol. (7), 50%
Vol. WFH + social dist (8), 50%
Vol. self isol. + social dist (9), 50%
reported deaths


120,000
100,000
80,000
60,000
40,000
20,000
0
Predicted Deaths
Mar 21
Apr 10
Apr 30
May 20
Jun 9
Jun 29
Jul 19
Aug 8
Aug 28
Day
Unmitigated (0)
Current Swedish mandates (1)
Mandates + household isol. (2)
Mandates + school closure (3)
Closures without distancing (4)
Closures with distancing (5)
Vol. self isol. + distancing (9), 30%


Vol. self-isolation + distancing (9), 30%
Vol. self-isolation + distancing (9), 50%
Vol. self-isolation + distancing (9), 75%
Vol. self isolation + distancing (9), 75%,10-day lag
Vol. self-isolation + distancing (9), 75%, 20-day lag
Vol. self-isolation + distancing (9), 75%, 30-day lag
60,000
50,000
40,000
30,000
20,000
10,000
0
Predicted Deaths
Mar 21
May 10
June 29
Aug 18
Day


a.
40,000
30,000
20,000
10,000
0
ICU Deman
Mar 21
May 10
June 29
Aug 18
Day
Current mandates
Vol. WFH (6), 100%
Vol. self isol. (7), 100%
Vol. WFH + social dist (8) 100%
Vol. self isol + social dist (9), 100%
Vol. WFH (6), 30%
Vol. self. isol (7), 30%
Vol. WFH + social dist (8), 30%
Vol. self. isol + social dist (9), 30%
Vol. WFH (6), 50%
Vol. self isol. (7), 50%
Vol. WFH + social dist (8), 50%
Vol. self isol. + social dist (9), 50%
Pre-pandemic ICU capacity
b.
40,000
30,000
20,000
10,000
0
ICU Demand
Mar 21
May 10
June 29
Aug 18
Day
Unmitigated (0)
Current Swedish mandates (1)
Mandates + household isol. (2)
Mandates + school closure (3)
Closures without distancing (4)
Closures with distancing (5)
Vol. self-isolation + distancing (9), 30%
pre-pandemic ICU capacity


a.
Sweden
Risk Ratio ICU:Death
20
15
10
5
0
ND
0-9
10-19
20-29
30-39
40-49
50-59
60-69
70-79
80-89
90-99
Age
b.
United States
Risk Ratio ICU:Death
20
15
10
5
0
ND
0-19
20-44
45-54
55-64
65-74
75-84
85-99
Age