Updated roadmap assessment: prior to delayed step 4

Rosanna C. Barnard, Nicholas G. Davies, Mark Jit & W. John Edmunds
London School of Hygiene & Tropical Medicine
7th July 2021

In this report we model Step 4 of the UK Government's Spring 2021 "Roadmap" out of lockdown in England occurring on the 19th of July 2021. To capture behavioural changes in response to the easing of restrictions, we consider low, medium and high scenarios for mobility levels resulting from implementing Step 4 of the roadmap, in addition to considering different reductions in self-protective measures following recent policy announcements related to mask wearing and self isolation. We consider scenarios for vaccine protection against and severity of the Delta B.1.617.2 variant, and scenarios with and without waning immunity. For each scenario considered, we fit the relative transmissibility of the Delta B.1.617.2 variant and project forwards until the end of 2021. This work builds upon modelling and assumptions used in our previous report. We make assumptions about the nature and impact of roadmap Step 4 which cannot be verified until policy decisions are finalised and behavioural responses can be measured.

There is still considerable uncertainty over the properties of the Delta B.1.617.2 variant, but all scenarios considered here estimate that the Delta B.1.617.2 variant possesses a substantial transmission advantage over the Alpha B.1.1.7 variant (a 40–80% increase in the reproduction number). All scenarios considered project a third wave of infection peaking in the late summer into the autumn of 2021 if roadmap Step 4 is enacted on 19th of July 2021. The intensity of the projected third wave varies substantially depending upon assumed levels of vaccine protection against the Delta B.1.617.2 variant, on the rate of social mixing following policy changes at Step 4 of the roadmap and on other factors such as reductions in self-protective measures and waning of immunity. Estimates from Public Health England and Public Health Scotland suggest an increased risk of hospitalisation associated with the Delta B.1.617.2 variant, and our scenarios assuming an 80% increase in severity for the Delta B.1.617.2 variant are able to fit the data better than scenarios assuming no increase in severity of Delta B.1.617.2. Owing to uncertainties related to the properties of the Delta B.1.617.2 variant, further close monitoring of the COVID-19 burden associated with Delta is essential for robust decision making.

Summary of findings

- Our modelling scenarios project a wave of COVID-19 transmission over the summer and autumn months of 2021. The timing and severity of such a wave depends on a number of factors including behaviour following the implementation of roadmap Step 4 on the 19th of July (both in terms of contact rates and the extent to which "COVID secure" behaviours remain), the true effectiveness and coverage of COVID-19 vaccines, the extent to which immunity to SARS-CoV-2 infection remains following natural infection and vaccination, and the severity of the Delta B.1.617.2 variant.
- Under most scenarios, this summer wave of transmission is expected to peak in August 2021. In some scenarios, a smaller secondary peak occurs in the autumn and winter

months of 2021, which is due to (i) the summer school holidays in England suppressing transmission from the end of July until September 2021 and (ii) assumed levels of seasonality (20% peak to trough) introduced from the 1st of April 2021 and waning immunity. In most cases, the projected peak is below the height of the winter peak, particularly for deaths, which are greatly reduced by vaccination.

- We project that roughly half of the hospitalisations and deaths occurring in the summer 2021 are likely to be in vaccinated individuals, depending upon vaccine coverage (Fig. 14). Admissions are projected to be split relatively evenly between the 45-64, 65-74 and 75+ year age groups, while deaths are likely to be concentrated in the 75+ age group (Fig. 15).
- These projections are subject to considerable uncertainty. It is not possible to accurately predict how mobility and contacts will change following the easing of restrictions. We have presented our results in terms of low, medium and high assumptions for mobility, in addition to considering relaxations in the protective measures individuals employ, and these make a considerable difference to the results.
- Furthermore, there remains enormous uncertainty in the characteristics of the Delta B.1.617.2 variant (in terms of immune escape and transmissibility) and the effectiveness of vaccines in preventing infection and serious disease. A range of scenarios is presented to cover these different possibilities.

Summary of changes since June 2021

- The analysis in this report builds on the work done in our previous report.
- We have updated our assumptions on vaccine protection against onward transmission following breakthrough infections in vaccinated individuals (see Tables 1, 3 and Table S1).
- We consider central and optimistic scenarios for the level of vaccine protection against the Delta B.1.617.2 SARS-CoV-2 variant (Table 3).
- We consider scenarios with and without waning of natural and vaccine induced immunity (Table 4). For scenarios with waning immunity, we have increased the length of protection so that 15% of individuals lose their protection in 1 year (previously assumed to be 6 months); this corresponds to a roughly 6-year average duration of natural or vaccine-derived protection.
- We consider scenarios with and without an increase in the severity of the Delta B.1.617.2 variant.
- For each scenario considered, we fit the introduction time and relative transmissibility of the Delta B.1.617.2 variant for each NHS England region.
- We have updated our length of hospital stay estimates using CO-CIN data; these estimates now vary by age in the model.
- We have updated our age-specific case fatality ratios to better match the observed distribution of deaths between age groups.

- We have updated the time individuals spend with first dose protection before moving to second dose protection using measured delays (data up to 30th June 2021) and improved the way the model reflects estimated vaccine coverage.

Modelling limitations & uncertainties

- The extent of the threat that the Delta B.1.617.2 SARS-CoV-2 variant poses remains unclear. Evidence is still emerging on its inherent transmission advantage, the levels of protection provided by COVID-19 vaccines and natural immunity against different outcomes and on any potential increase in severity. We have based our scenarios related to Delta B.1.617.2 on the best available evidence, but this information may change as more data is collected.
- These results are dependent on as yet unverifiable assumptions regarding the impact of policy changes at roadmap Step 4 on individuals' behaviour, in addition to the extent to which individuals will continue employing self-protective measures such as mask wearing and physical distancing. It is unclear how predictive levels of mobility are on contact making behaviour that leads to transmission events, and in particular how this relationship might vary during different times of the year. It is also unclear that increases in transmission attributed to the Delta B.1.617.2 SARS-CoV-2 variant apply uniformly to all types of contacts.
- It is unclear to what extent schools are contributing to transmission. We have assumed that the introduction of mass testing and mask wearing in schools in England from March 2021 resulted in an additional 30% reduction in transmission resulting from school related contacts. However, since the 17th of May 2021 face mask use is no longer required in secondary school classrooms, and it is unclear to what extent face mask wearing in secondary schools continues. We do not assume any increase in school related transmission since this policy change on the 17th of May.
- There is little evidence available related to the levels of cross protection that prior infection with pre-existing SARS-CoV-2 variants such as Alpha B.1.1.7 might provide against infection with Delta B.1.617.2. In this analysis, we assume that prior infection with pre-existing or Alpha B.1.1.7 SARS-CoV-2 variants provides 100% cross protection against infection with Delta B.1.617.2.
- Levels of vaccine protection are assumed to be consistent across all age groups in the model. However, it is possible that vaccine protection differs across age groups.
- There is limited data regarding the effect that COVID-19 vaccines have on reducing onward transmission following breakthrough infections (when an individual with vaccine induced protection becomes infected). We rely on one study to parametrise our assumptions related to vaccine protection against onward transmission.
- It is unclear how much seasonality affects SARS-CoV-2 transmission, both in relation to behavioural changes that influence transmission and in relation to the ability of the SARS-CoV-2 virus to persist and spread. For the scenarios considered here, we assume 20% peak to trough seasonality to capture these effects.
- There are a number of uncertainties related to the rollout of COVID-19 vaccines in England. Changes in the speed of vaccine rollout, the uptake of vaccines, and policy changes (such as vaccination of children) will influence transmission dynamics. We do

not consider the vaccination of children nor any additional booster vaccine doses in late 2021. Due to substantial uncertainties in estimation of the resident population of the UK and the geographical redistribution of individuals within the UK following the pandemic, there is also uncertainty related to true vaccine coverage.

- Our central scenario assumes that 15% of individuals with immunity conferred from prior infection with SARS-CoV-2 and from COVID-19 vaccination lose this protection within 1 year; this corresponds to a 6-year average duration of natural or vaccine-derived protection. There is limited evidence related to the timescales at which natural and vaccine induced immunity wanes, as well as any potential differences in rates of waning for natural and vaccine induced immunity. It is likely that protection against severe outcomes is longer lasting than protection against reinfection, but we do not model any additional protection against severe outcomes when an individual in the model loses their immunity.

Methods & assumptions

Basic model assumptions

We use an age- and geographically-structured deterministic compartmental model of SARS-CoV-2 transmission. Geographic structure is by NHS England region and age groups are divided into 5-year age bands from 0–4 to 70–74 years with an additional age group comprising individuals aged 75 years and over. Further details of the model and how it has been fitted to data are given in Davies et al. 2020 (Lancet Inf Dis) and Davies et al. 2021 (Science). The model uses Google Community Mobility data to track mobility in various settings: workplaces, retail & recreation venues, transit stations, and grocery & pharmacy locations.

School openings and closings are accounted for in contacts among school-aged children, university-aged young adults and school/university staff. We assume that schools in England follow their traditional schedules (i.e. are closed during half-term periods and over summer holiday periods). However, to reflect the introduction of mass testing within educational facilities in the Spring of 2021, we have assumed an additional 30% reduction in transmission related to educational settings following the reopening of schools on 8th March 2021. This reduction in transmission is reflected in the model with a 30% reduction in school-related contacts. The relationship between mobility data and social contact rates is derived from the historical relationship between Google Community Mobility indices and social contact rates as measured by the CoMix study in 2020 (Davies et al. 2020, Lancet Inf Dis).

The model tracks three co-circulating SARS-CoV-2 variants: the Delta B.1.617.2, Alpha B.1.1.7 and pre-existing variants. The model structure has been extended from a similar two-variant model structure (Davies et al. 2021, Science) to consider three variants explicitly. The model is fitted to PCR prevalence as measured by the Office for National Statistics (ONS); seroprevalence as measured by REACT-2, UK Biobank, and the ONS; daily incidence of

COVID-19 deaths, hospital admissions, hospital bed occupancy, and ICU admissions as provided by PHE and the NHS (Davies et al. 2020 Lancet Inf Dis); the frequency of *S* gene target failure up to 15th February 2021 to capture the spread of Alpha B.1.1.7 (Davies et al. 2021, Science); and the frequency of lineage B.1.617.2 in sequenced Pillar 2 cases up to 2nd June 2021 to capture the spread of Delta B.1.617.2.

We use PHE data recording the number of first and second vaccine doses delivered by age, geography and vaccine product from the 8th of December 2020 to the 30th of June 2021 to inform the fraction of vaccinated individuals in each age group, NHS England region and by vaccine type and dose over time. Vaccine schedules are generated by combining vaccines already delivered with future schedules generated based on a number of assumptions (see 'Vaccine assumptions') and ensuring that all first doses are followed up with equivalent second doses according to the measured delays between first and second doses already delivered (see also 'Vaccine schedules' for a full description).

The age-specific probability of clinical symptoms is adopted from Davies et al (Nature Medicine, 2020) using data from 6 countries. The age-specific probability of hospital admission, ICU admission, and death given infection are fitted to data from England, with the relative rates by age group based on data collected by a large meta-analysis of the COVID-19 infection fatality rate (Levin et al., Eur J Epi 2020) and based on data collected by ISARIC (the CO-CIN study) for England (Davies et al., Lancet Inf Dis 2020), then adjusted to better match observed hospitalisations and deaths in England. Each of these age-specific probabilities of severe outcomes is allowed to vary over the course of the epidemic in England and vary between pre-existing variants and Alpha B.1.1.7. For the third variant Delta B.1.617.2, we consider scenarios where the probability of severe outcomes is assumed to be the same as and 1.8 times the severity of Alpha B.1.1.7. This increased severity is in line with preliminary estimates from Public Health England and Public Health Scotland in PHE Technical Briefing 17 and preceding reports which find an increased risk of hospitalisation for cases who are *S*-gene positive (Scotland) or had sequencing confirmed Delta B.1.617.2 infection (England).

Roadmap assumptions

We base our assumptions on how social contact rates might be expected to change at Step 4 of the Roadmap by referring to historical Google Community Mobility data and making assumptions about future mobility changes (Figures 1 and 2). We consider "low", "medium", and "high" scenarios for future changes in mobility, with various assumptions made across four mobility indices (Grocery and pharmacy, Retail and recreation, Transit stations and Workplaces).

Grocery and pharmacy mobility is currently above baseline levels, so we assume this metric reaches 1.05 times baseline levels for "low", "medium" and "high" scenarios implementing roadmap Step 4. For retail and recreation, our "low" scenario assumes mobility will return to the level recorded in August 2020 following roadmap Step 4. We assume that retail and recreation mobility will reach 0.95 for the "medium" scenario and 1.05 for the "high" scenario following

roadmap Step 4, assuming that pre-pandemic baseline levels are exceeded due to good weather and high spirits.

We do not expect either Transit or Workplace mobility to return to pre-pandemic baseline levels. Following roadmap Step 4, our “low” scenario assumes that transit-related mobility reaches similar levels to late September 2020. The “medium” and “high” scenarios assume transit-related mobility reaches 80 and 90% of baseline levels respectively. Workplace mobility levels are already close to or at their highest point since pre-pandemic baseline levels were recorded in early 2020. Our “low” scenario assumes a slight increase of workplace mobility to 80% of baseline, whilst the “medium” and “high” scenarios assume workplace-related mobility reaches 85% and 90% of baseline levels, respectively.

Although we assume future mobility changes for “low”, “medium” and “high” scenarios, we assume that an additional level of control is maintained via contact tracing and social distancing (i.e. through physical distancing, mask wearing and hand hygiene), equivalent to a reduction in R of 20-30% in total depending on the NHS England region, as fitted for each NHS England region during the summer of 2020. We include sensitivity analyses considering various levels of reductions in this additional level of control (see Figure 5).

Vaccine schedules

Vaccine schedules are generated by combining PHE data on vaccines delivered up to 30th June 2021 in England with future schedules based on a number of assumptions related to vaccine supply and vaccine uptake (see ‘Vaccine assumptions’ section). The number of future doses supplied for each day in the schedule are distributed into the seven NHS England regions according to the population size of each region. The number of vaccine doses per region per day are initially allocated to age groups in the model according to the existing age distribution of all doses delivered. Beginning with the oldest age group, the allocated number of doses per day, per region and per age group are divided into specified proportions of vaccine products relevant to each age group (see ‘Vaccine mix’ section). Second doses are delivered according to the measured gap between first and second doses already delivered. Once all required second doses have been allocated, leftover doses for that day, region and age group are delivered as first doses up to the relevant age-specific uptake limit (set at 80% for individuals under 40 and as per vaccines delivered to date in 40+ year olds). If doses are remaining after second and first doses have been delivered, these leftover doses are carried over to either the next age group down, the next NHS England region, the next day, or are not allocated in the schedule and are recorded as leftover doses.

Vaccine assumptions

Vaccine effectiveness

We base our vaccine effectiveness assumptions on the latest available evidence. These may be subject to change in future work, as new evidence emerges. We currently treat individuals who have been and will be vaccinated with Moderna vaccines the same as individuals receiving

Pfizer vaccines. We model individuals who have received different vaccine products (e.g. AstraZeneca and Pfizer/Moderna) and one or two vaccine doses separately, assuming separate efficacy estimates for each category. We model vaccine protection against five separate outcomes: infection, disease (i.e. symptomatic infection), hospitalisation, mortality and onward transmission following a breakthrough infection (i.e. when an individual who has vaccine protection becomes infected). We assume the same vaccine effectiveness for the first two SARS-CoV-2 variants considered in the model (pre-Alpha B.1.1.7 and Alpha B.1.1.7), shown in Table 1. Table S1 in the Supplementary Material section shows a summary of the relevant evidence we have used to guide our assumptions on vaccine effectiveness against Alpha B.1.1.7 and pre-existing variants of SARS-CoV-2.

To arrive at estimates for vaccine protection against the Delta B.1.617.2 variant, we rely on PHE data calculating vaccine effectiveness against symptomatic infection for *S*-gene target negatives or Alpha B.1.1.7 and *S*-gene target positives or Delta B.1.617.2 (see reference in Table 2) and on recent PHE estimates on vaccine effectiveness. Firstly, we calculate the relative reduction in vaccine effect against symptomatic infection between Alpha B.1.1.7 or *S*-gene target negatives and Delta B.1.617.2 or *S*-gene positives, for each dose of each vaccine product (Table 2). These estimates are used to downgrade our assumed vaccine protection against infection and disease with pre- and Alpha B.1.1.7 variants (shown in Table 1) to arrive at central and optimistic estimates for vaccine protection against the same outcomes with Delta B.1.617.2 (Table 3). The central and optimistic scenarios considered assume 100% and 80% of the relative reduction shown in Table 2, respectively. For vaccine protection against severe outcomes (hospitalisation and mortality) with Delta B.1.617.2, our central and optimistic scenarios assume either the same or improved levels of vaccine protection compared to assumed values for pre- and Alpha B.1.1.7 variants. Our optimistic scenario assumes that vaccine protection against hospitalisation and mortality after a first vaccine dose (regardless of vaccine product) is 85%, with protection assumed to reach 96% against hospitalisation and 98% against mortality following a second dose of either vaccine. For both the central and optimistic scenarios, we assume that vaccine protection against onward transmission remains unchanged from the levels assumed for pre-existing and Alpha B.1.1.7 variants.

Vaccine uptake

Vaccine uptake is modelled as per first dose vaccine uptake up to 30th June 2021 for individuals aged 40 years and above (Figure 3), and is assumed to reach 80% for individuals under 40 years old. In some age groups we calculate that vaccine coverage has exceeded population size estimates, so we include sensitivity analyses imposing additional vaccine coverage limits of 95% and 98% (see Figure 8).

Table 1 - Assumptions for vaccine effectiveness against all outcomes (pre-Alpha B.1.1.7 and Alpha B.1.1.7 variants)

Outcome	**Vaccine effectiveness**			
	*Pfizer-BioNTech**		*Oxford-AstraZeneca*	
	1 dose	2 doses	1 dose	2 doses
Infection	**0.7**	**0.85**	**0.67**	**0.68**
Disease	**0.7**	**0.89**	**0.67**	**0.78**
Hospitalisation	**0.845**	**0.9**	**0.845**	**0.9**
Mortality	**0.845**	**0.95**	**0.845**	**0.95**
Onward transmission	**0.47**	**0.57**	**0.47**	**0.57**
Delay to efficacy	28 days	14 days	28 days	14 days
*We assume that the Moderna mRNA-1273 vaccine confers the same levels of protection as the Pfizer-BioNTech vaccine				

Table 2 - Vaccine effectiveness for Pfizer BioNTech BNT162b2 and Oxford AstraZeneca ChAdOx1 vaccines against symptomatic infection with *S*-gene target negatives (B.1.1.7) and *S*-gene target positives (B.1.617.2), see Table 2 of Lopez Bernal et al.

		Adjusted vaccine effectiveness, B.1.1.7 or S-gene target negative	Adjusted vaccine effectiveness, B.1.617.2 or S-gene target positive	Relative reduction in vaccine effect
Pfizer BioNTech BNT162b2	Dose 1	49.2% (42.6% to 55.0%)	33.2% (8.3% to 51.4%)	**32.5%**
	Dose 2	93.4% (90.4% to 95.5%)	87.9% (78.2% to 93.2%)	**5.9%**
Oxford AstraZeneca ChAdOx1	Dose 1	51.4% (47.3% to 55.2%)	32.9% (19.3% to 44.3%)	**36.0%**
	Dose 2	66.1% (54.0% to 75.0%)	59.8% (28.9% to 77.3%)	**9.5%**

Table 3 - Assumptions for vaccine effectiveness against all outcomes (Delta B.1.617.2)

Outcome	Vaccine effectiveness			
	Pfizer-BioNTech		*Oxford-AstraZeneca*	
	1 dose	2 doses	1 dose	2 doses
Infection[^]	**0.4725** (0.518)	**0.7999** (0.8098)	**0.4288** (0.4770)	**0.6154** (0.6283)
Disease[^]	**0.4725** (0.518)	**0.8375** (0.8480)	**0.4288** (0.4770)	**0.7059** (0.7207)
Hospitalisation[^]	**0.845** (0.85)	**0.9** (0.96)	**0.845** (0.85)	**0.9** (0.96)
Mortality[^]	**0.845** (0.85)	**0.95** (0.98)	**0.845** (0.85)	**0.95** (0.98)
Onward transmission[^]	**0.47**	**0.57**	**0.47**	**0.57**
Delay to efficacy	28 days	14 days	28 days	14 days

[^]Central assumptions are shown in bold, with optimistic assumptions shown below in brackets where assumed values differ from central assumptions. Central assumptions reduce vaccine effectiveness against infection and disease by the appropriate relative reduction in vaccine effect shown in Table 2, but assume protection against hospitalisation and mortality remains at the same levels as assumed for Alpha B.1.1.7, shown in Table 1. For optimistic assumptions, we reduce vaccine effectiveness against infection and disease by 0.8 times the appropriate relative reduction shown in Table 2, but assume increased protection against hospitalisation and mortality relative to the levels assumed for pre- and Alpha B.1.1.7. Both central and optimistic scenarios assume the same vaccine effectiveness against onward transmission as has been assumed for pre- and Alpha B.1.1.7.

Vaccine rollout

Future vaccine rollout follows a Cabinet Office agreed scenario, with an average of roughly 2 million doses per week in England (Fig. 3). First doses are followed up with equivalent second doses according to measured delays between first and second doses using data up to 30th June 2021.

Vaccine mix

The following proportions of each vaccine product are used in the vaccine schedules projected forwards:

- 75% Pfizer and 25% Moderna for <40 year olds
- 60% AstraZeneca, 30% Pfizer and 10% Moderna for 40-49 year olds
- Actual mix of AstraZeneca, Pfizer and Moderna first doses already delivered (using data on vaccines delivered up to 30th June 2021) for 50+ year olds

Waning immunity

We consider scenarios with and without waning of protection from SARS-CoV-2 infection developed from natural infection and vaccination. For all scenarios with waning immunity, we assume that rates of waning are identical for all three virus variants considered in the model. We assume that both natural and vaccine induced immunity wane at identical rates (Table 4). We further assume that waning of immunity against different endpoints (infection, disease, hospitalisation, deaths and onward transmission) occurs at the same rate. We also assume that rates of waning are identical across all age groups. Many of these assumptions are likely to not hold in practice, but there is currently an absence of data on differential rates of immunity against different outcomes, from different routes (vaccines and naturally occuring) and for different population groups.

Table 4 - Waning immunity scenarios

Description	Assumed values (**waning**)	Assumed values (**no waning**)
Waning of natural immunity	log(0.85)/-365, corresponding to 85% protection after 365 days = 1 year	0
Waning of vaccine induced immunity (second dose to susceptible / naive)	log(0.85)/-365, corresponding to 85% protection after 365 days = 1 year	0
Waning of vaccine induced immunity (first dose to susceptible / naive and second dose to first dose)	0	0

Variant of concern Delta B.1.617.2

Our analysis considers a third SARS-CoV-2 variant which has been parametrised in relation to the Delta / B.1.617.2 variant of concern, also referred to as VOC-21APR-02. We use sequenced Pillar 2 cases to inform the proportion of the Delta B.1.617.2 variant circulating versus the proportion of pre-Alpha B.1.1.7 and Alpha B.1.1.7 variants. We consider central and optimistic scenarios related to the level of vaccine protection against the Delta B.1.617.2 variant (Table 3). For each of these scenarios and for each NHS England region the model fits an introduction time relative transmissibility of the Delta B.1.617.2 variant (compared to the Alpha B.1.1.7 variant) to best match the sequencing data.

Results

The projected effect of implementing roadmap Step 4 in England on the 19th of July 2021 is shown for various scenarios considering combinations of behaviour changes, vaccine effectiveness estimates, vaccine uptake, waning immunity and severity of the Delta B.1.617.2 variant (Figures 4-10). We project a wave of COVID-19 transmission over the summer and autumn months of 2021 for all scenarios considered, with varying levels of hospital admissions, hospital bed occupancy and mortality depending on the assumptions considered.

For more pessimistic scenarios assuming large behavioural changes following roadmap Step 4 or assuming low vaccine uptake, hospital admissions and hospital bed occupancy may exceed the peak levels recorded during the previous wave in January 2021 (Figures 4, 5, 6, 8). However, for the same scenarios, we project that the burden on mortality will be lower than the peak levels recorded during the previous wave in January 2021. Contrasting more pessimistic with more optimistic assumptions, we project significant differences in the sizes of the waves of transmission over the next few months (Figure 4). Tables 5-10 summarise the projected total number of hospital admissions, deaths, and infections; and the peak number of hospital beds occupied, intensive care unit (ICU) beds occupied, and infections for the scenarios considered in Figures 5-10.

Across all of the sensitivity analyses considered, the biggest variation in projected waves of transmission occurs in relation to behavioural changes. These were considered in terms of a reduction in self-protective measures—which include Test, Trace and Isolate, physical distancing, mask wearing, meeting outdoors, and other measures independent of actual interpersonal contact rates (Figure 5)—and in terms of changes in mobility (and thus contact rates) following roadmap Step 4 on the 19th of July 2021 (Figure 6). An 80% reduction in self-protective measures is projected to lead to a substantial wave of transmission; for example, in a scenario with waning immunity and central estimates for vaccine efficacy, this reduction leads to 250,000 hospital admissions and 46,000 deaths between 1 July and 31 December 2021 (Table 5).

Model fits to data on COVID-19 daily deaths, hospital admissions, hospital beds occupied, ICU beds occupied and PCR prevalence as measured by the Office for National Statistics (ONS) across all seven NHS England regions are shown in Figure 11. We fitted the model for every combination of vaccine effectiveness (central and optimistic, see Table 3), waning immunity (Table 4) and severity of Delta B.1.617.2, either assuming the same levels of severity as for the Alpha B.1.1.7 variant or 1.8 times the severity for Alpha B.1.1.7. For each NHS England region, we fit the introduction time and relative transmissibility of both the Alpha B.1.1.7 and the Delta B.1.617.2 variants.

Figure 12 shows a summary of the projected peak number of COVID-19 hospital beds occupied, peak number of ICU beds occupied, peak number of infections, total hospital admissions, total deaths and total infections across the various sensitivities considered. This illustrates how outcomes vary depending upon modelling assumptions, and accordingly, can be

used to estimate the extent to which the magnitude of the projected third wave may vary depending upon the various uncertain properties of vaccine effectiveness and uptake, behaviour changes following step 4, and the severity of the Delta variant.

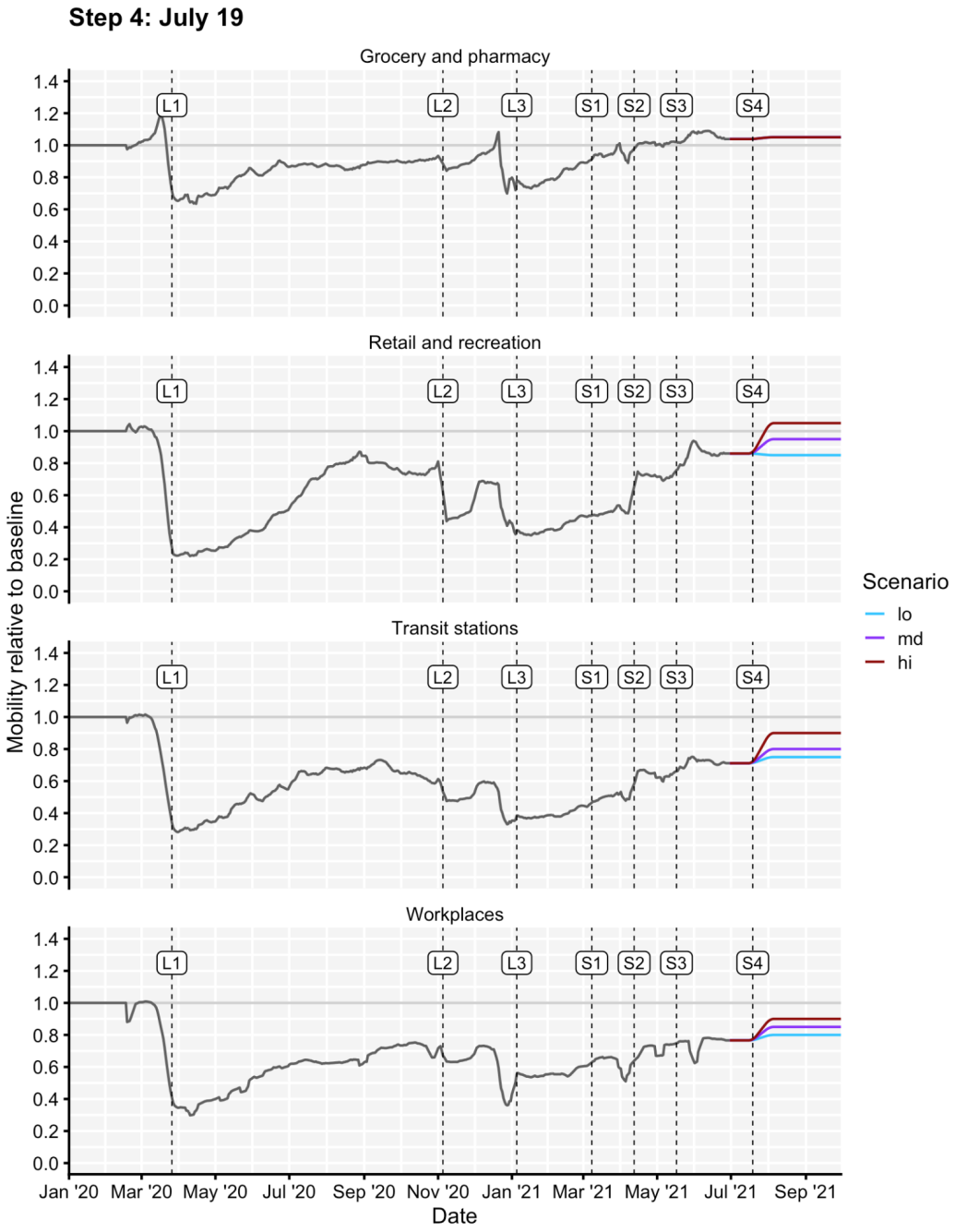

Figure 1 - Historic Google Community Mobility data (grey) and assumed future mobility in England for low (blue), medium (purple) and high (red) scenarios used for model projections implementing roadmap Step 4 on 19th July 2021. Mobility indices are measured relative to baseline mobility levels recorded during early 2020, prior to the COVID-19 pandemic. The beginning of each lockdown and each roadmap Step is marked with a vertical dashed line.

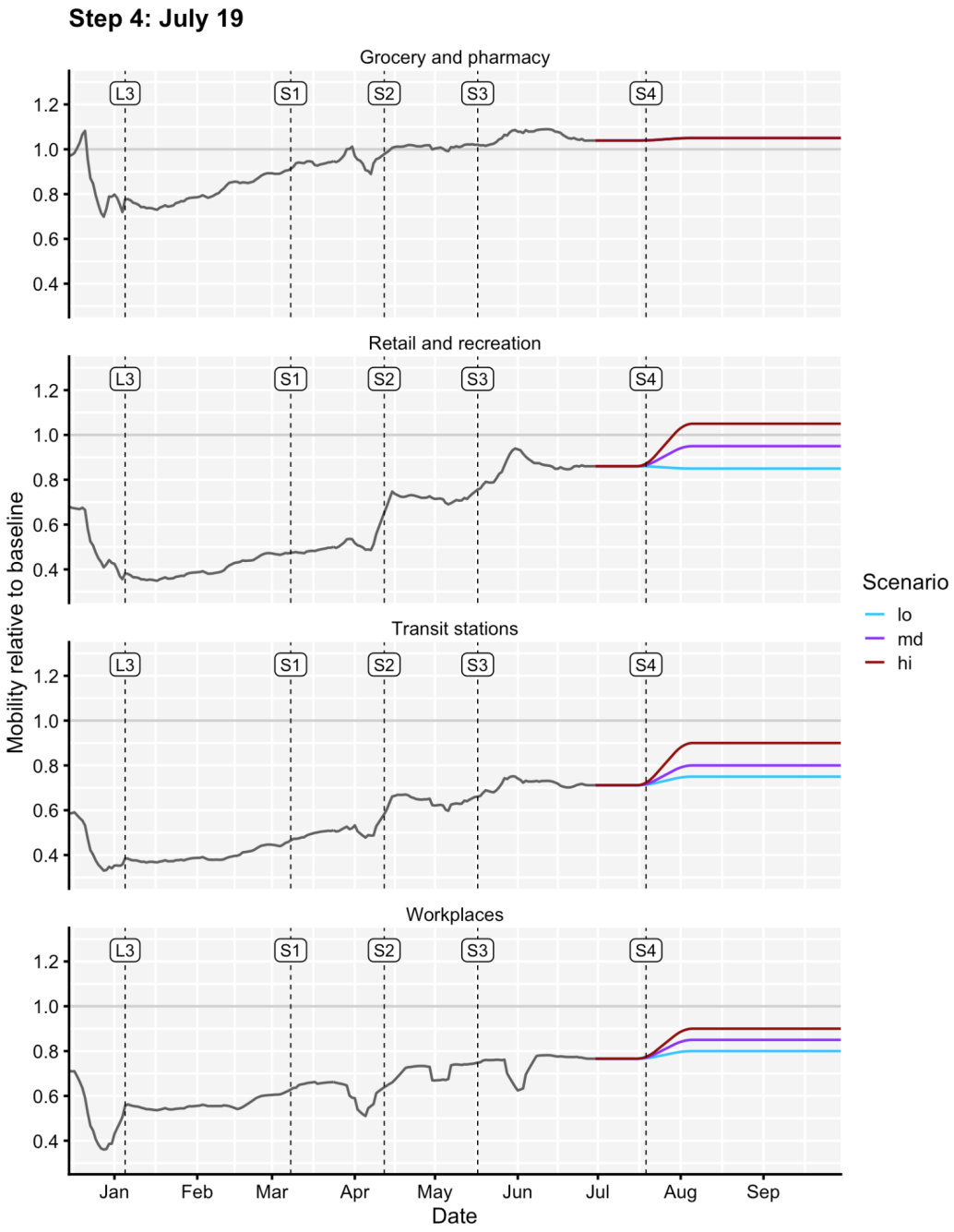

Figure 2 - Zoomed-in view of Figure 1. Google Community Mobility data (grey) and assumed future mobility in England for low (blue), medium (purple) and high (red) scenarios used for model projections implementing roadmap Step 4 on 19th July 2021. Mobility indices are measured relative to baseline mobility levels recorded during early 2020, prior to the COVID-19 pandemic. The beginning of the third national lockdown and each roadmap Step in England is marked with a vertical dashed line.

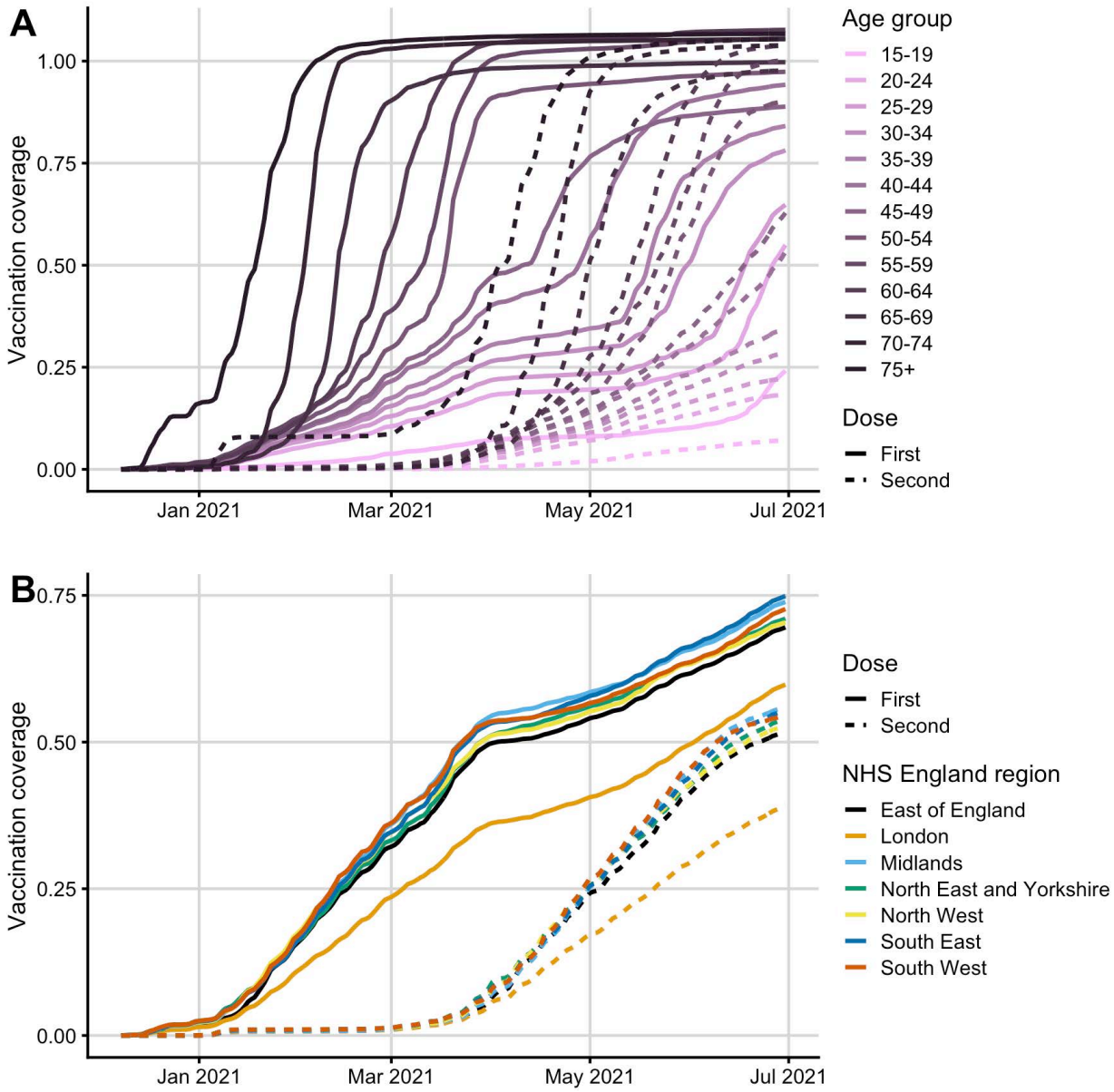

Figure 3 - COVID-19 vaccine coverage in England between 8th December 2020 and 30th June 2021, by age group (A) and NHS England region (B), using PHE data from 2nd July 2021. Solid lines show first dose coverage and dashed lines show second dose coverage, with coverage being calculated across all three vaccine products (Pfizer, AstraZeneca and Moderna) currently being administered in England. Low vaccine coverage for London is partly due to the lower average age of inhabitants of London, and may be partly due to an overestimation of the number of people living in London, as the population size estimates used date to mid-2018.

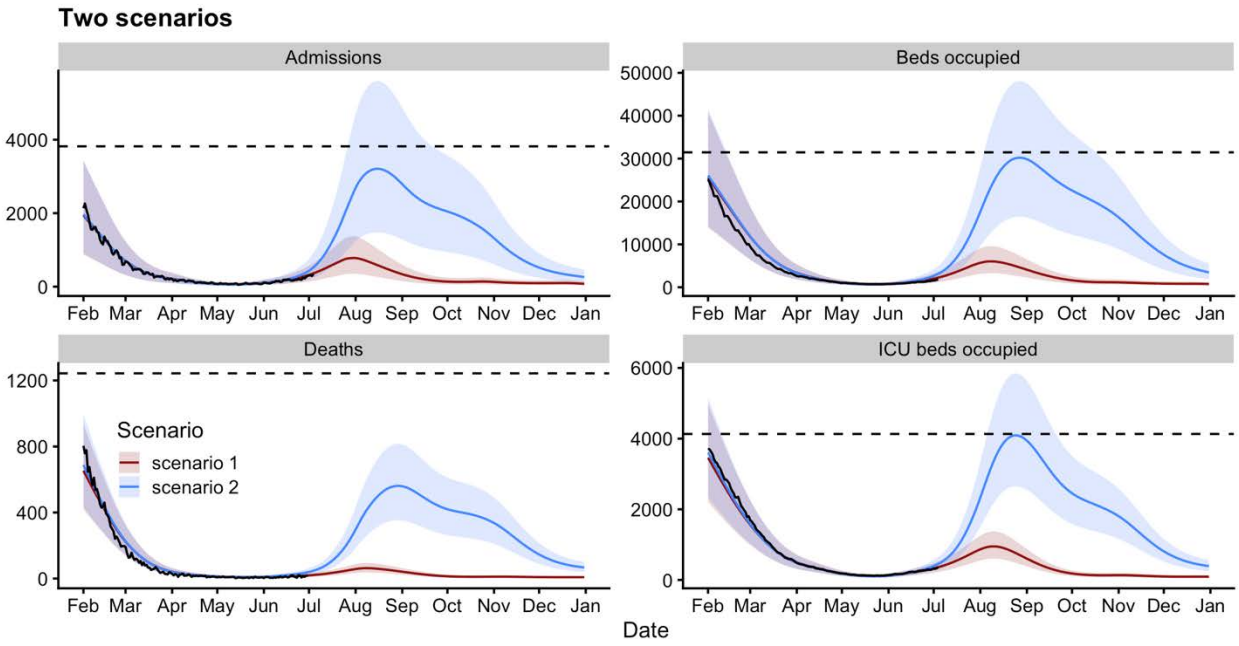

Figure 4 - Model scenarios for the number of COVID-19 hospital admissions, hospital beds occupied, deaths, and intensive care unit (ICU) beds occupied in England following implementation of roadmap Step 4 on the 19th of July 2021. Two scenarios are plotted to demonstrate the wide range of possible epidemic trajectories resulting from different modelling assumptions, with projections shown until the end of 2021. Scenario 1 (red) considers: medium levels of mobility changes occurring after roadmap Step 4 (Figures 1 and 2); a 20% reduction in self-protective measures; no waning of natural and vaccine induced immunity; and optimistic assumptions on vaccine effectiveness against the Delta B.1.617.2 variant (Table 3). Scenario 2 (blue) considers: high levels of mobility changes occurring after roadmap Step 4 (Figures 1 and 2); a 60% reduction in self-protective measures; 15% of individuals with natural and vaccine induced immunity waning after 1 year (Table 4); and central assumptions on vaccine effect against the Delta B.1.617.2 variant (Table 3). Dashed lines show the height of the winter 2021 wave.

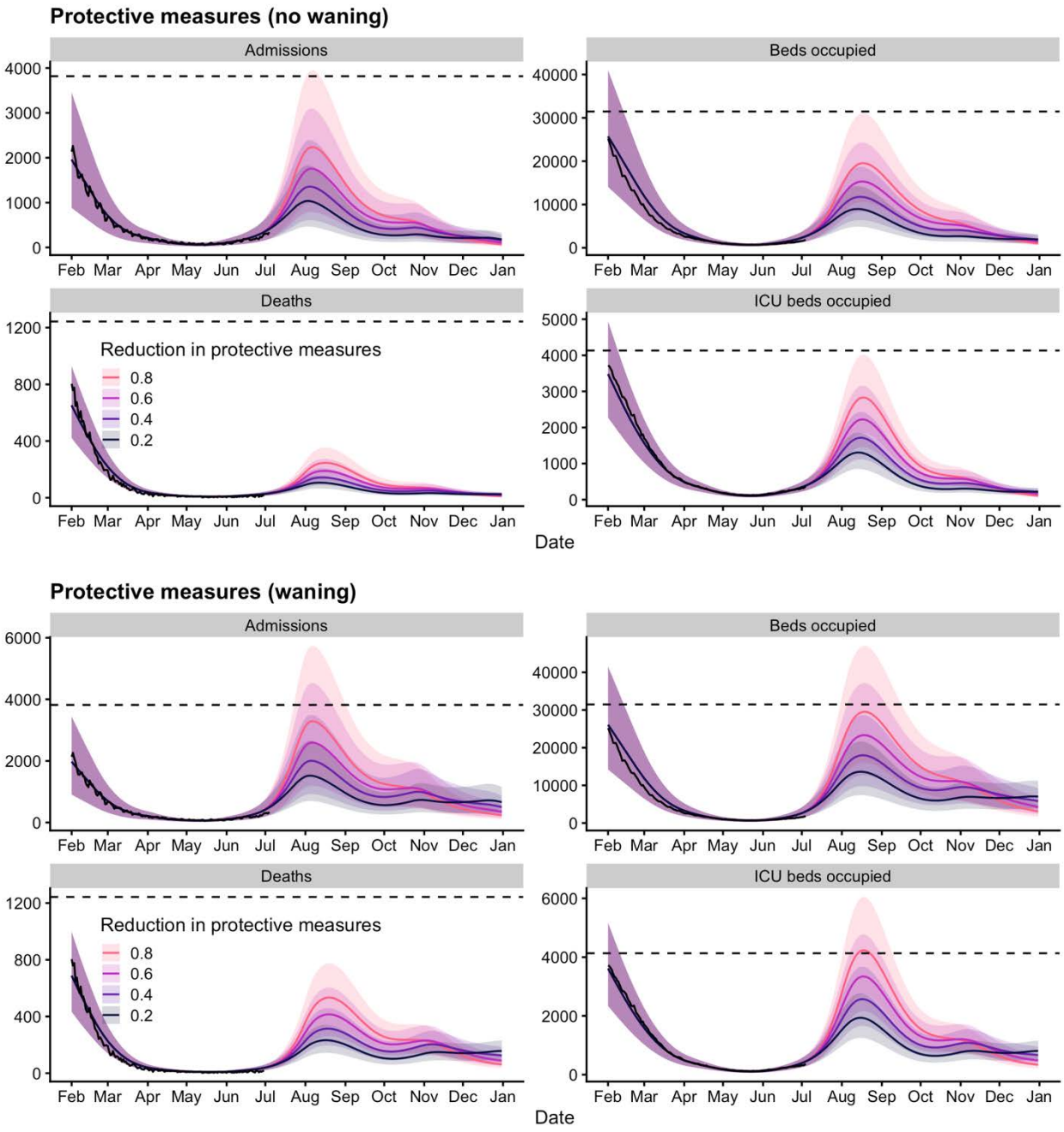

Figure 5 - Model projections for the number of COVID-19 hospital admissions, hospital beds occupied, deaths, and intensive care unit (ICU) beds occupied in England following implementation of roadmap Step 4 on the 19th of July 2021. Four scenarios are plotted which demonstrate the effect on transmission of assuming a 20%, 40%, 60% or 80% reduction in current levels of self-protective measures following the implementation of roadmap Step 4, with projections shown until the end of 2021. These self-protective measures were estimated by the LSHTM transmission model to reduce the effective reproduction number R by approximately 25% and comprise the effect of policies and behaviours which suppress transmission such as mask wearing, test, trace and isolate (TTI) and physical distancing. Scenarios shown here assume: no waning (top) versus waning (bottom) of natural or vaccine induced immunity (Table 4); 1.8-fold increased severity of Delta relative to Alpha; central vaccine effectiveness assumptions against Delta B.1.617.2 (Table 3); and assume medium changes in mobility following implementation of roadmap Step 4 on the 19th of July 2021. Dashed lines show the height of the winter 2021 wave.

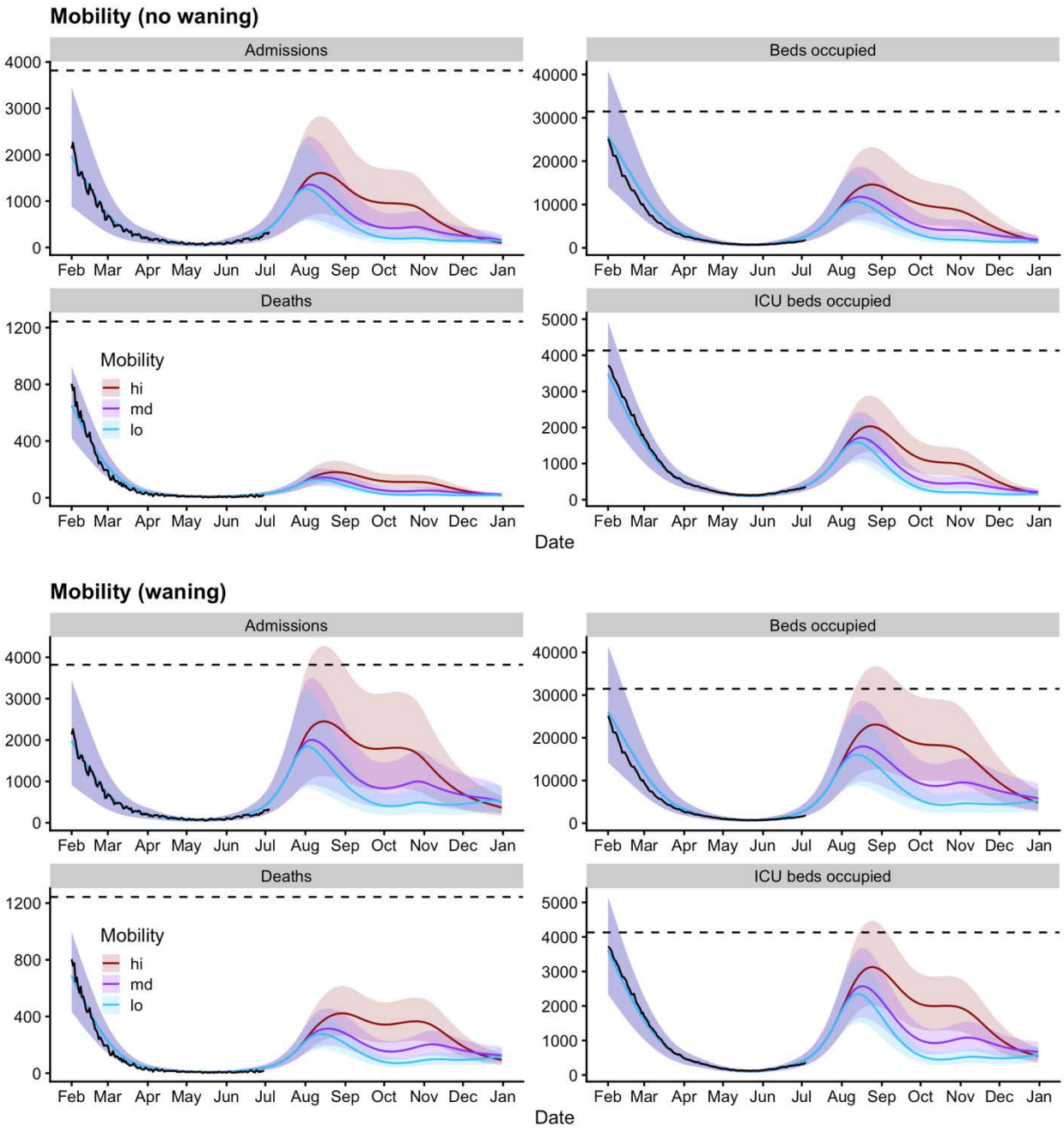

Figure 6 - Model projections for the number of COVID-19 hospital admissions, hospital beds occupied, deaths, and intensive care unit (ICU) beds occupied in England following implementation of roadmap Step 4 on the 19th of July 2021. Three scenarios are plotted which demonstrate the effect on transmission of assuming low (blue), medium (purple), and high (red) changes in mobility (see Figures 1 and 2) following the implementation of roadmap Step 4, with projections shown until the end of 2021. Scenarios shown here assume: no waning (top) versus waning (bottom) of natural or vaccine induced immunity (Table 4); 1.8-fold increased severity of Delta relative to Alpha; central vaccine effectiveness assumptions against Delta B.1.617.2 (Table 3); and a 40% reduction in personal protective measures. Dashed lines show the height of the winter 2021 wave.

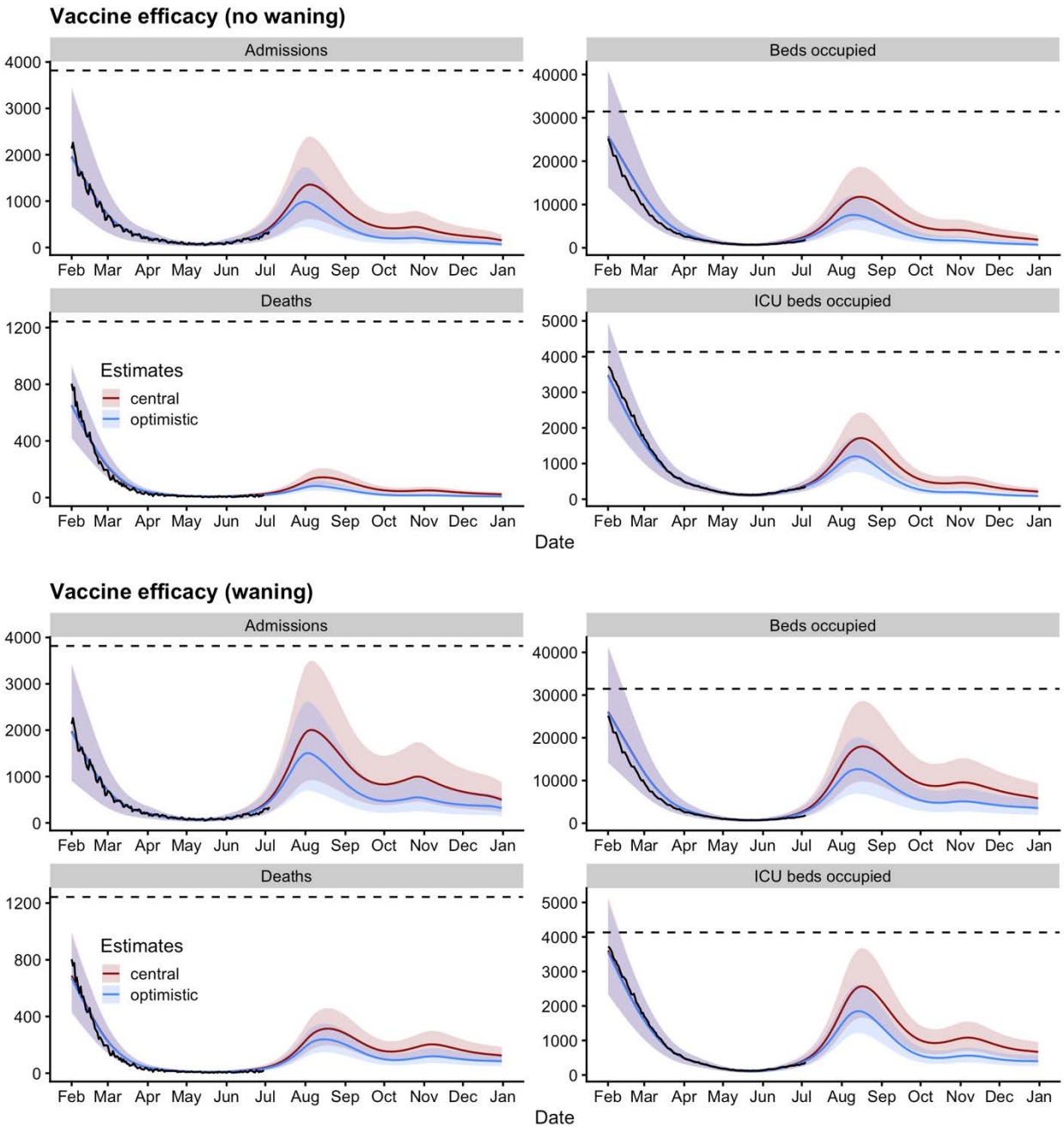

Figure 7 - Model projections for the number of COVID-19 hospital admissions, hospital beds occupied, deaths, and intensive care unit (ICU) beds occupied in England following implementation of roadmap Step 4 on the 19th of July 2021. Two scenarios are plotted which demonstrate the effect on transmission of assuming central (red) and optimistic (blue) scenarios for vaccine effectiveness against the Delta B.1.617.2 variant (see Table 3), with projections shown until the end of 2021. Scenarios shown here assume: no waning (top) versus waning (bottom) of natural or vaccine induced immunity (Table 4); 1.8-fold increased severity of Delta relative to Alpha; medium changes in mobility following implementation of roadmap Step 4 on the 19th of July 2021; and a 40% reduction in personal protective measures. Dashed lines show the height of the winter 2021 wave.

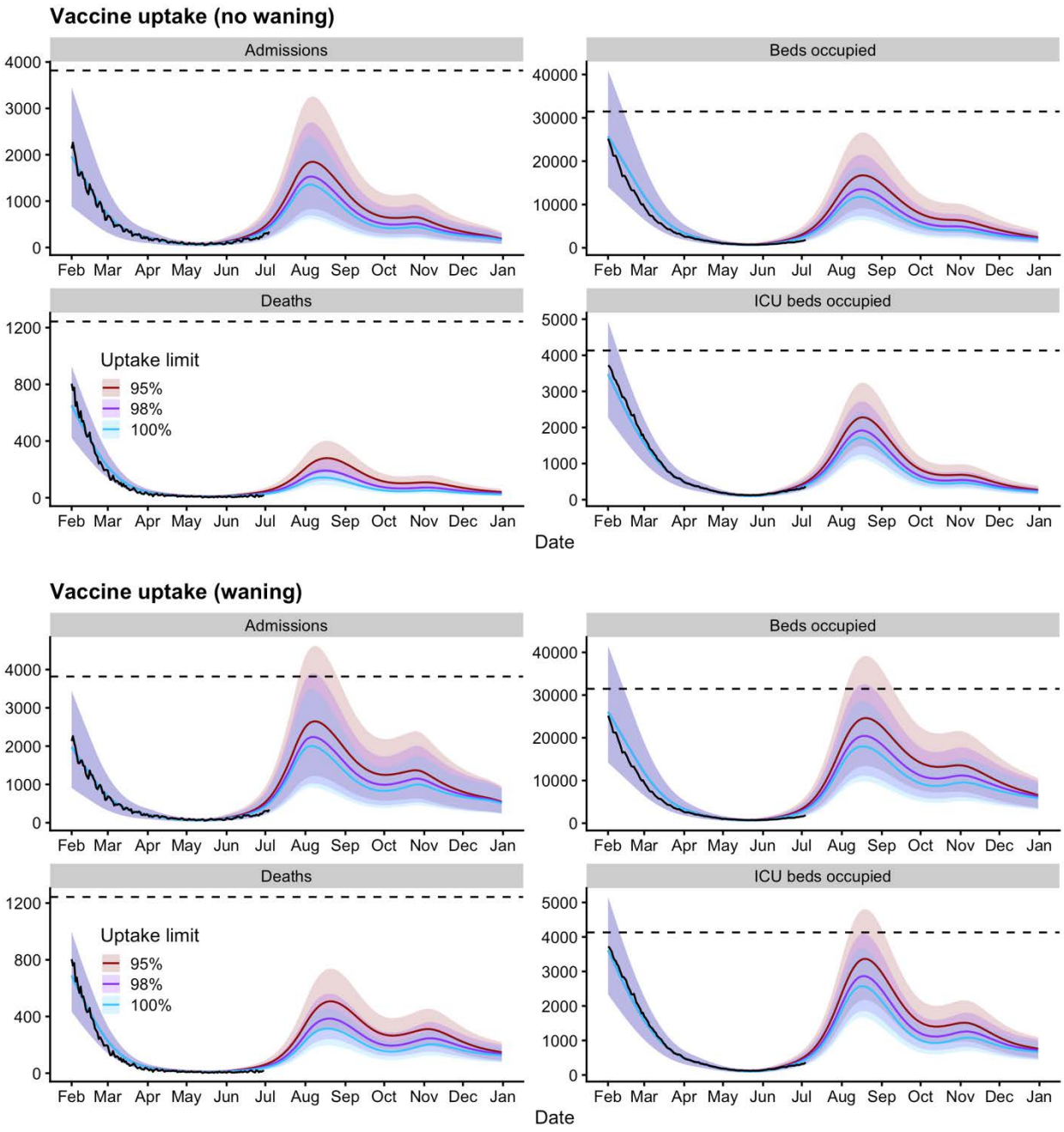

Figure 8 - Model projections for the number of COVID-19 hospital admissions, hospital beds occupied, deaths, and intensive care unit (ICU) beds occupied in England following implementation of roadmap Step 4 on the 19th of July 2021. Three scenarios are plotted which demonstrate the effect on transmission of limiting vaccine uptake to 95% (red), 98% (purple) and 100% (blue) of population sizes, with projections shown until the end of 2021. Here, the 100% (blue) scenario assumes that PHE immunisations data is accurate. In some cases, this data suggests that more people have been vaccinated than are estimated to be in the relevant population group. We therefore consider sensitivity to actual vaccine uptake by including additional scenarios limiting uptake to lower levels. Scenarios shown here assume: no waning (top) versus waning (bottom) of natural or vaccine induced immunity (Table 4); 1.8-fold increased severity of Delta relative to Alpha; central vaccine effectiveness assumptions against Delta B.1.617.2 (Table 3); medium changes in mobility following implementation of roadmap Step 4 on the 19th of July 2021; and a 40% reduction in personal protective measures. Dashed lines show the height of the winter 2021 wave.

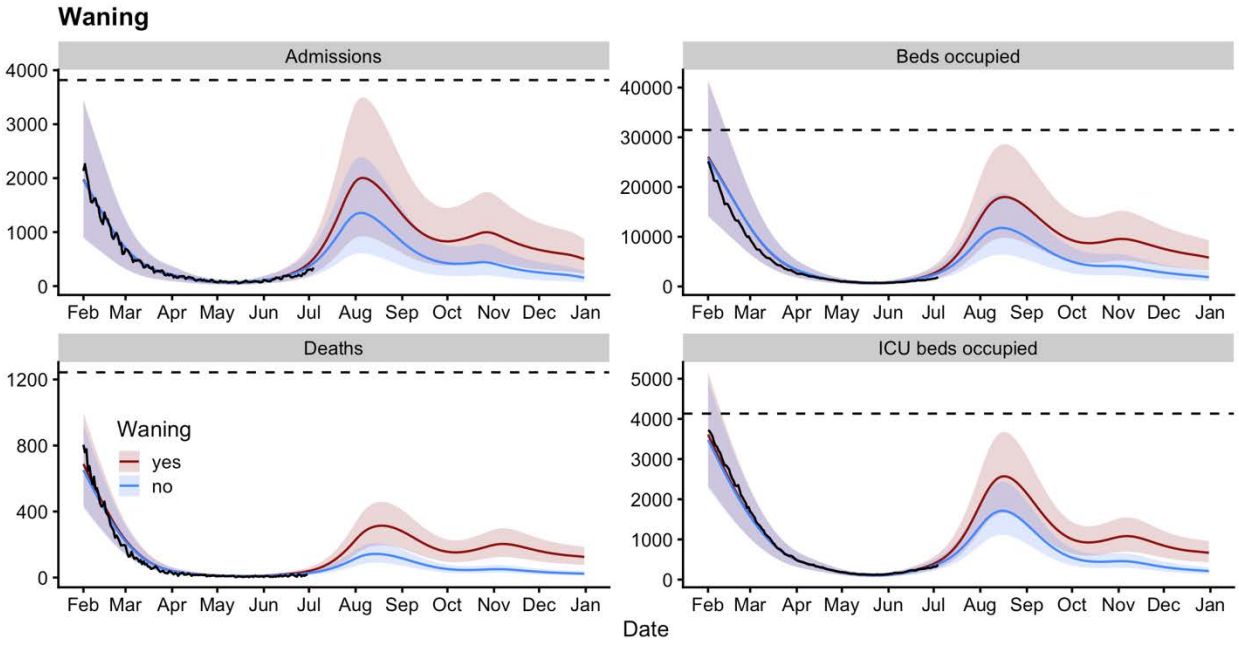

Figure 9 - Model projections for the number of COVID-19 hospital admissions, hospital beds occupied, deaths, and intensive care unit (ICU) beds occupied in England following implementation of roadmap Step 4 on the 19th of July 2021. Two scenarios are plotted which demonstrate the effect on transmission of scenarios with (red) and without (blue) waning immunity, with projections shown until the end of 2021. The scenario with waning immunity assumes that 15% of individuals with natural and vaccine-induced immunity lose their protection within 1 year. Scenarios shown here assume: 1.8-fold increased severity of Delta relative to Alpha; central vaccine effectiveness assumptions against Delta B.1.617.2 (Table 3); medium changes in mobility following implementation of roadmap Step 4 on the 19th of July 2021; and a 40% reduction in personal protective measures. Dashed lines show the height of the winter 2021 wave.

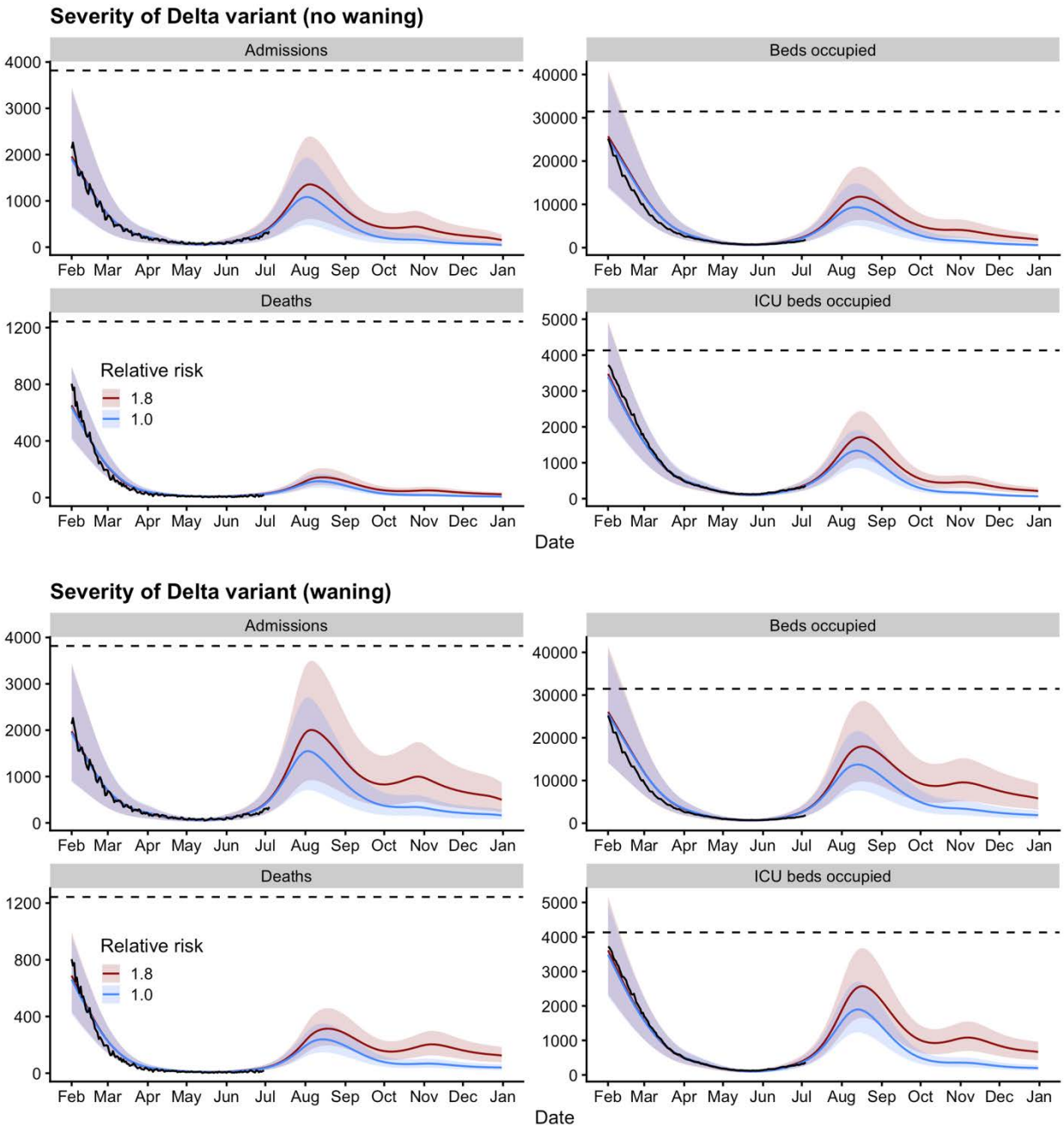

Figure 10 - Model projections for the number of COVID-19 hospital admissions, hospital beds occupied, deaths, and intensive care unit (ICU) beds occupied in England following implementation of roadmap Step 4 on the 19th of July 2021. Two scenarios are plotted which demonstrate the effect on transmission of assuming the Delta B.1.617.2 variant is associated with a 1.8-fold increase in severity compared to the Alpha B.1.1.7 variant (red), and assuming no increase in severity relative to Alpha B.1.1.7 (blue), with projections shown until the end of 2021. Scenarios shown here assume: no waning (top) versus waning (bottom) of natural or vaccine induced immunity (Table 4); central vaccine effectiveness assumptions against Delta B.1.617.2 (Table 3); medium changes in mobility following implementation of roadmap Step 4 on the 19th of July 2021; and a 40% reduction in personal protective measures. Dashed lines show the height of the winter 2021 wave.

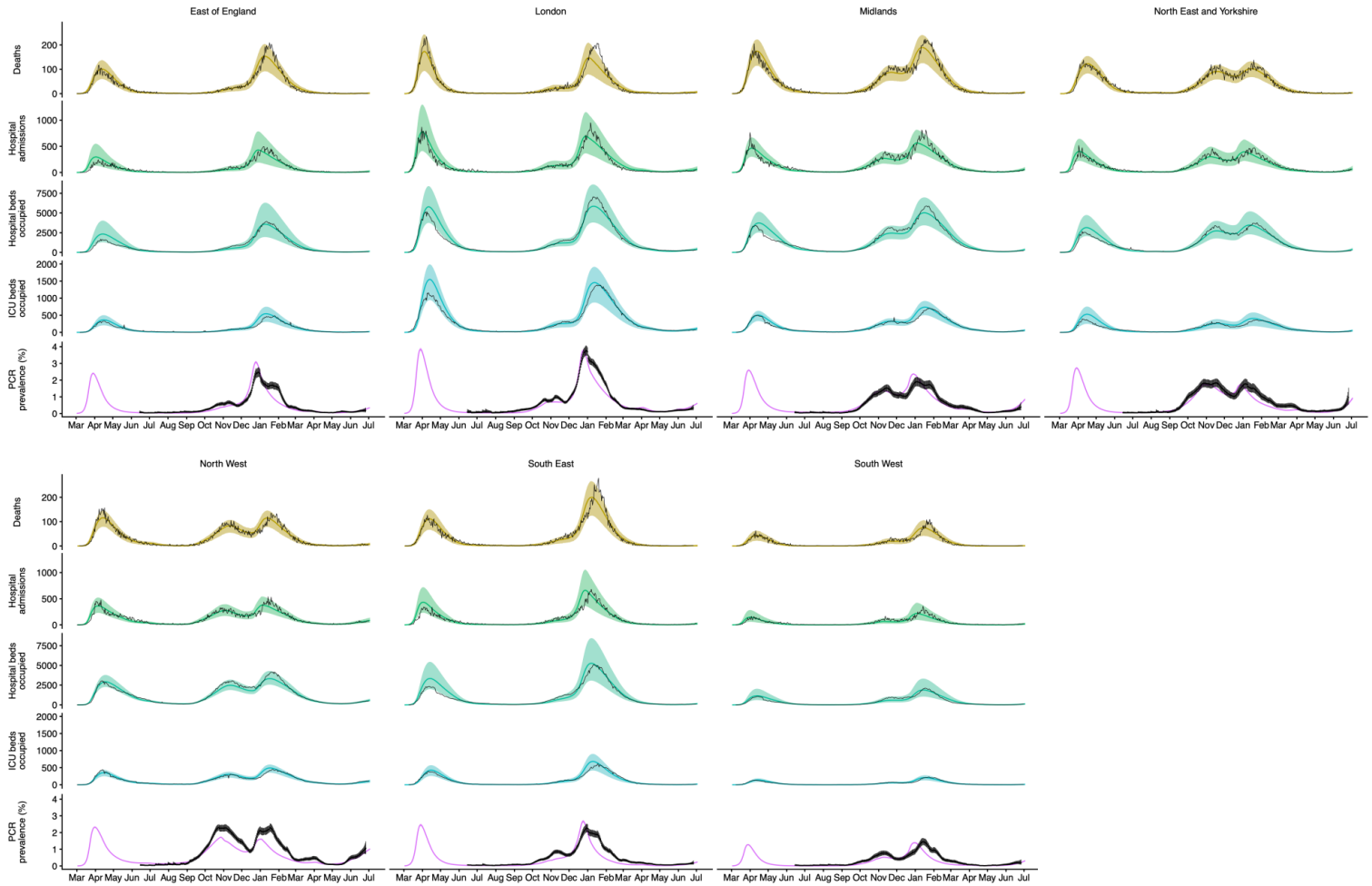

Figure 11 - Model fits to data on COVID-19 deaths, hospital admissions, hospital beds occupied, intensive care unit (ICU) beds occupied and PCR prevalence as measured by the Office for National Statistics across all seven NHS England regions between March 2020 and July 2021. The fitted model assumes no waning of immunity (Table 4) and increased severity of and central vaccine effectiveness against the Delta B.1.617.2 variant (Table 3). Black lines show data while coloured lines and shaded regions show model-projected median and 90% credible intervals.

Table 5 - Summary of projections for total COVID-19 hospital admissions, deaths, and infections, and peak hospital bed occupancy, ICU bed occupancy, and daily infection incidence for England, over the time period 1st July – 31st December 2021, considering different reductions in protective measures (Figure 5).

No waning

Reduction in protective measures	Total Admissions	Total Deaths	Total Infections	Peak Beds occupied	Peak ICU beds occupied	Peak Infections
0.8	160,000	19,000	9,900,000	20,000	2,800	220,000
0.6	130,000	15,000	8,600,000	15,000	2,200	180,000
0.4	110,000	12,000	7,200,000	12,000	1,700	140,000
0.2	82,000	9,000	5,700,000	9,000	1,300	110,000

Waning

Reduction in protective measures	Total Admissions	Total Deaths	Total Infections	Peak Beds occupied	Peak ICU beds occupied	Peak Infections
0.8	250,000	46,000	13,000,000	30,000	4,200	280,000
0.6	220,000	40,000	11,000,000	23,000	3,300	230,000
0.4	190,000	34,000	10,000,000	18,000	2,600	180,000
0.2	150,000	27,000	8,300,000	14,000	1,900	140,000

Table 6 - Summary of projections for total COVID-19 hospital admissions, deaths, and infections, and peak hospital bed occupancy, ICU bed occupancy, and daily infection incidence for England, over the time period 1st July – 31st December 2021, considering different levels of mobility following implementing roadmap Step 4 on 19th July 2021 (Figure 6).

No waning

Mobility	Total Admissions	Total Deaths	Total Infections	Peak Beds occupied	Peak ICU beds occupied	Peak Infections
hi	160,000	18,000	9,500,000	15,000	2,000	140,000
md	110,000	12,000	7,200,000	12,000	1,700	140,000
lo	81,000	8,900	5,700,000	11,000	1,600	140,000

Waning

Mobility	Total Admissions	Total Deaths	Total Infections	Peak Beds occupied	Peak ICU beds occupied	Peak Infections
hi	270,000	50,000	13,000,000	23,000	3,100	180,000
md	190,000	34,000	10,000,000	18,000	2,600	180,000
lo	140,000	24,000	8,000,000	16,000	2,300	180,000

Table 7 - Summary of projections for total COVID-19 hospital admissions, deaths, and infections, and peak hospital bed occupancy, ICU bed occupancy, and daily infection incidence for England, over the time period 1st July – 31st December 2021, considering central and optimistic scenarios for vaccine effectiveness against the Delta B.1.617.2 variant (Figure 7).

No waning

Estimates	Total Admissions	Total Deaths	Total Infections	Peak Beds occupied	Peak ICU beds occupied	Peak Infections
central	110,000	12,000	7,200,000	12,000	1,700	140,000
optimistic	66,000	5,800	7,300,000	7,600	1,200	160,000

Waning

Estimates	Total Admissions	Total Deaths	Total Infections	Peak Beds occupied	Peak ICU beds occupied	Peak Infections
central	190,000	34,000	10,000,000	18,000	2,600	180,000
optimistic	130,000	23,000	9,500,000	13,000	1,900	190,000

Table 8 - Summary of projections for total COVID-19 hospital admissions, deaths, and infections, and peak hospital bed occupancy, ICU bed occupancy, and daily infection incidence for England, over the time period 1st July – 31st December 2021 considering 95%, 98% and 100% of recorded vaccine uptake (Figure 8).

No waning

Uptake limit	Total Admissions	Total Deaths	Total Infections	Peak Beds occupied	Peak ICU beds occupied	Peak Infections
95%	150,000	24,000	7,800,000	17,000	2,300	150,000
98%	120,000	16,000	7,400,000	14,000	1,900	150,000
100%	110,000	12,000	7,200,000	12,000	1,700	140,000

Waning

Uptake limit	Total Admissions	Total Deaths	Total Infections	Peak Beds occupied	Peak ICU beds occupied	Peak Infections
95%	260,000	53,000	11,000,000	25,000	3,400	190,000
98%	220,000	41,000	10,000,000	20,000	2,900	180,000
100%	190,000	34,000	10,000,000	18,000	2,600	180,000

Table 9 - Summary of projections for total COVID-19 hospital admissions, deaths, and infections, and peak hospital bed occupancy, ICU bed occupancy, and daily infection incidence for England, over the time period 1st July – 31st December 2021, considering scenarios with and without waning immunity (Figure 9).

Waning	Total Admissions	Total Deaths	Total Infections	Peak Beds occupied	Peak ICU beds occupied	Peak Infections
yes	190,000	34,000	10,000,000	18,000	2,600	180,000
no	110,000	12,000	7,200,000	12,000	1,700	140,000

Table 10 - Summary of projections for total COVID-19 hospital admissions, deaths, and infections, and peak hospital bed occupancy, ICU bed occupancy, and daily infection incidence for England, over the time period 1st July – 31st December 2021, considering scenarios with and without increased severity of Delta B.1.617.2 relative to Alpha B.1.1.7 (Figure 10).

No waning

Relative risk	Total Admissions	Total Deaths	Total Infections	Peak Beds occupied	Peak ICU beds occupied	Peak Infections
1.8	110,000	12,000	7,200,000	12,000	1,700	140,000
1.0	70,000	8,000	7,900,000	9,300	1,300	190,000

Waning

Relative risk	Total Admissions	Total Deaths	Total Infections	Peak Beds occupied	Peak ICU beds occupied	Peak Infections
1.8	190,000	34,000	10,000,000	18,000	2,600	180,000
1.0	110,000	19,000	10,000,000	14,000	1,900	230,000

No waning

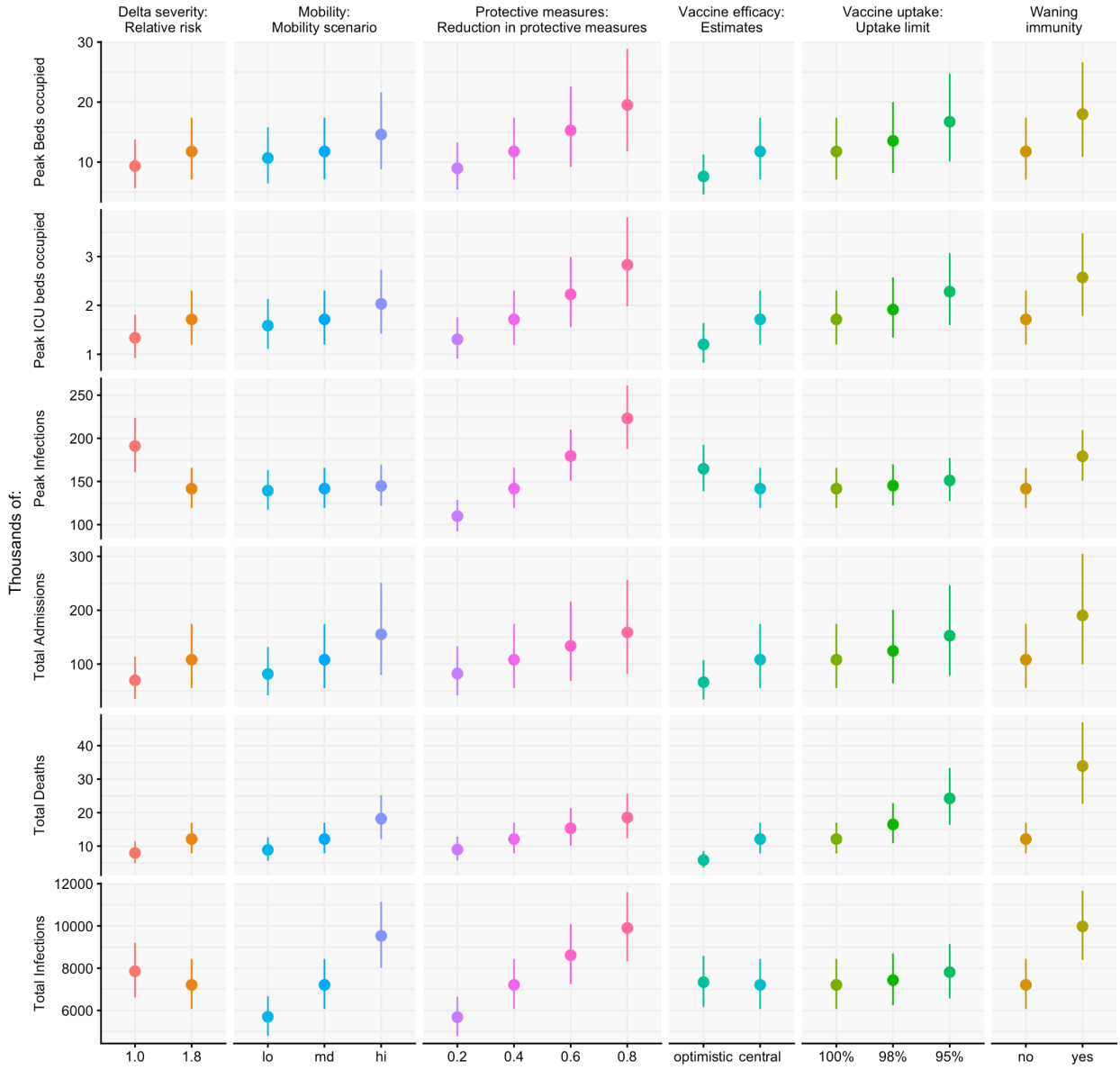

Figure 12, no waning immunity - Summary plot for scenarios showing peak number of hospital beds occupied, peak number of ICU beds occupied, peak number of infections, total hospital admissions, total deaths and total infections (in thousands) across different sensitivities considered for England. This plot illustrates the sensitivities of model scenarios to modelling assumptions. From left to right, we consider differences in: the assumed severity of the Delta B.1.617.2 variant relative to the Alpha B.1.1.7 variant; low, medium and high scenarios for mobility levels following roadmap Step 4 on the 19th of July 2021 (Figures 1 and 2); 20%, 40%, 60% and 80% reductions in protective measures following the relaxation at Step 4; optimistic and central assumptions for vaccine effectiveness against Delta B.1.617.2 (Table 3); sensitivities for vaccine uptake (set at 100% of measured uptake, and capped at 98% and 95% respectively); and scenarios with and without waning of natural and vaccine-induced immunity (Table 4). Central scenarios shown here assume (unless otherwise specified and explicitly varied): waning immunity; 1.8-fold increased severity of Delta relative to Alpha; central vaccine effectiveness assumptions against Delta B.1.617.2 (Table 3); medium changes in mobility following implementation of roadmap Step 4 on the 19th of July 2021; and a 40% reduction in personal protective measures.

Waning

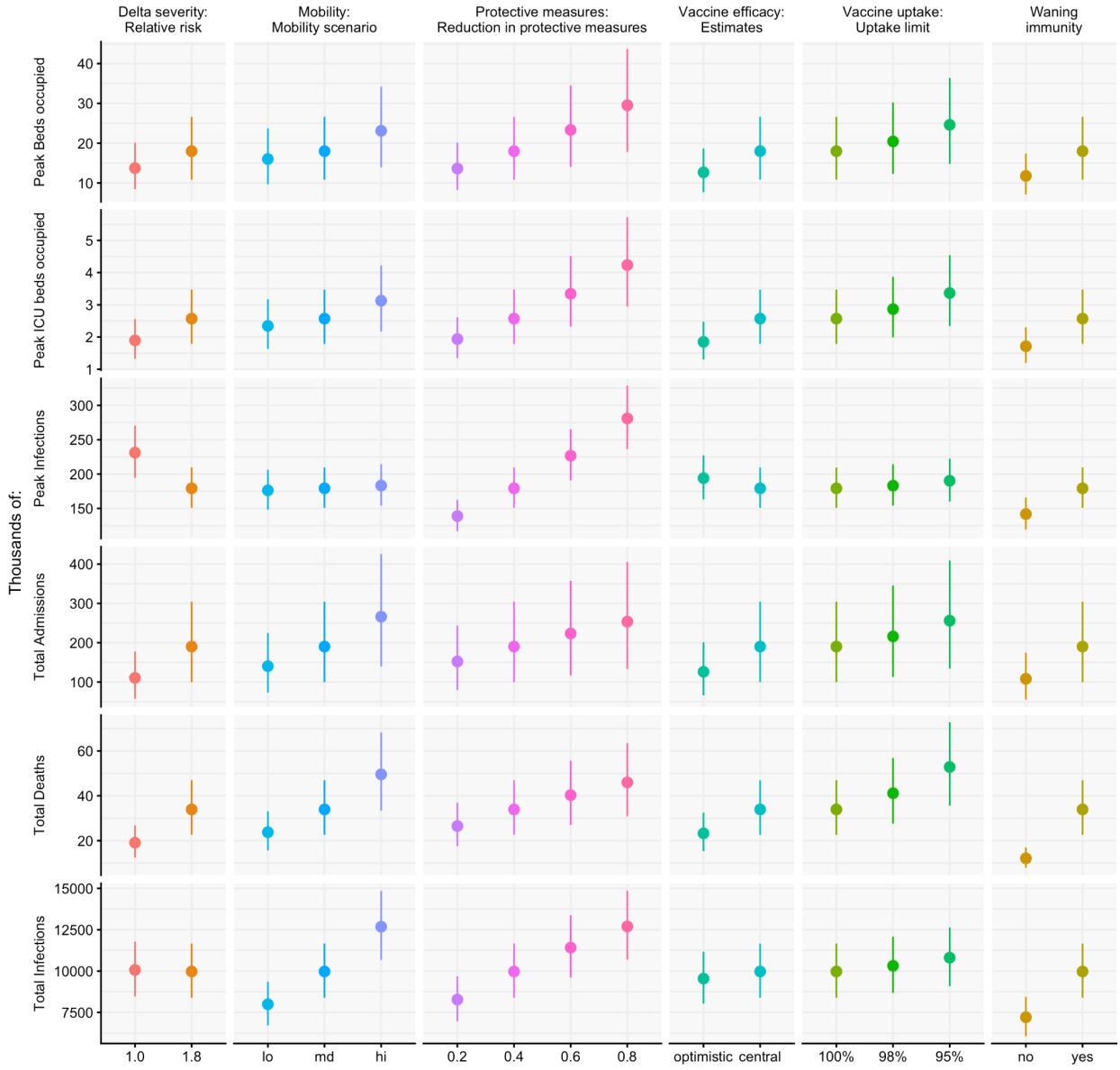

Figure 13, with waning immunity - Summary plot for scenarios showing peak number of hospital beds occupied, peak number of ICU beds occupied, peak number of infections, total hospital admissions, total deaths and total infections (in thousands) across different sensitivities considered for England. This plot illustrates the sensitivities of model scenarios to modelling assumptions. From left to right, we consider differences in: the assumed severity of the Delta B.1.617.2 variant relative to the Alpha B.1.1.7 variant; low, medium and high scenarios for mobility levels following roadmap Step 4 on the 19th of July 2021 (Figures 1 and 2); 20%, 40%, 60% and 80% reductions in protective measures following the relaxation at Step 4; optimistic and central assumptions for vaccine effectiveness against Delta B.1.617.2 (Table 3); sensitivities for vaccine uptake (set at 100% of measured uptake, and capped at 98% and 95% respectively); and scenarios with and without waning of natural and vaccine-induced immunity (Table 4). Central scenarios shown here assume (unless otherwise specified and explicitly varied): waning immunity; 1.8-fold increased severity of Delta relative to Alpha; central vaccine effectiveness assumptions against Delta B.1.617.2 (Table 3); medium changes in mobility following implementation of roadmap Step 4 on the 19th of July 2021; and a 40% reduction in personal protective measures.

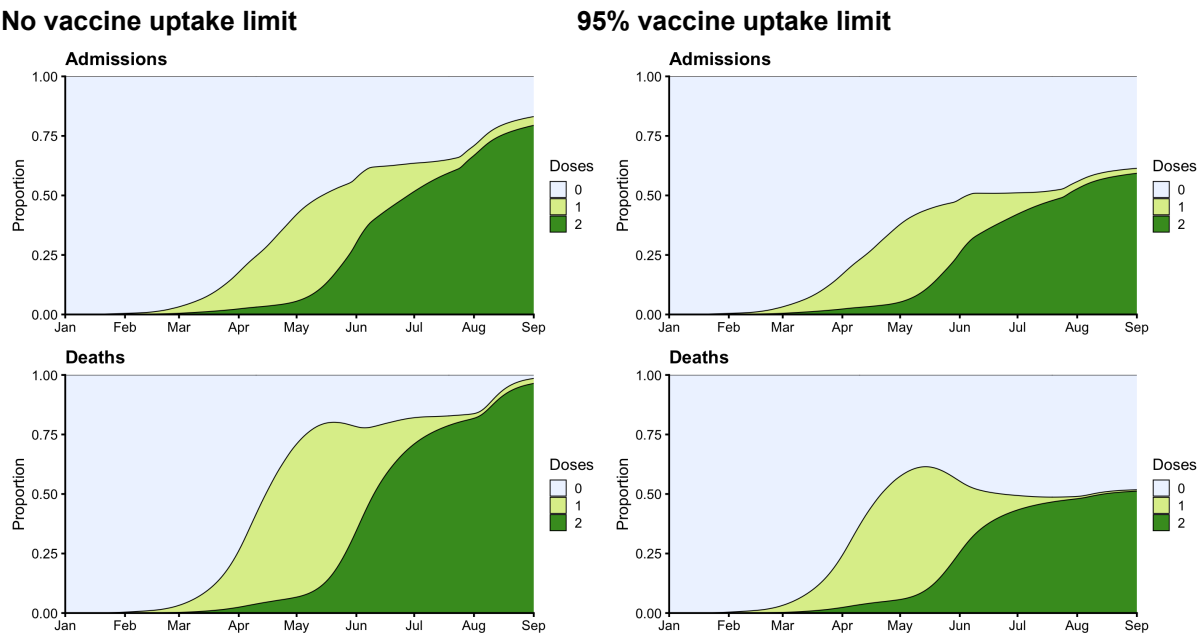

Figure 14 - Proportion of admissions and deaths by vaccine status. Scenarios shown here assume: no waning immunity; 1.8-fold increased severity of Delta relative to Alpha; central vaccine effectiveness assumptions against Delta B.1.617.2 (Table 3); medium changes in mobility following implementation of roadmap Step 4 on the 19th of July 2021; and a 40% reduction in personal protective measures. The left column shows high vaccine uptake as reported by the NHS relative to population sizes as reported by the ONS, and so likely overestimates vaccine coverage; the right column shows a scenario in which vaccine uptake is limited to 95% in each age group.

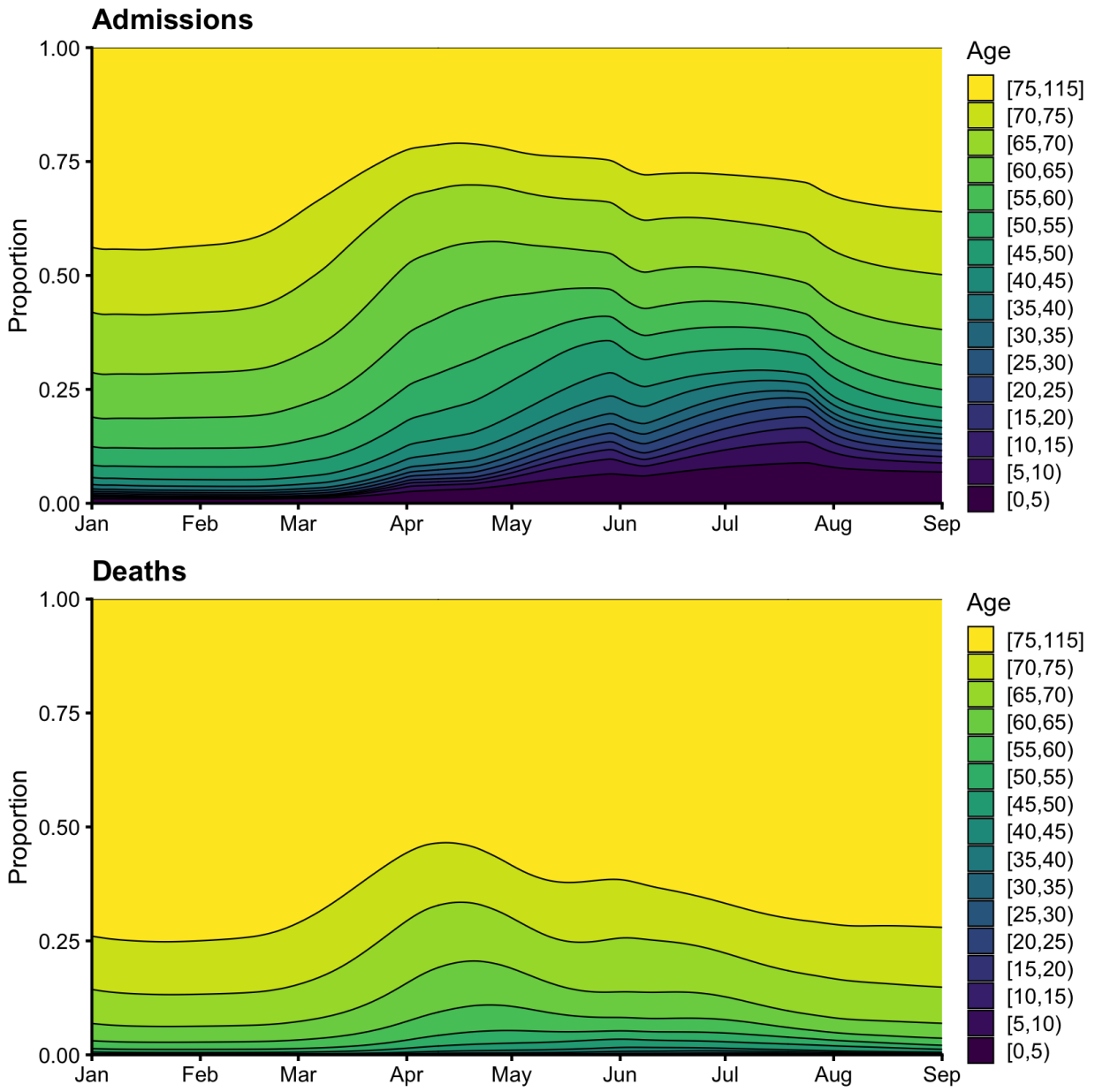

Figure 15 - Proportion of admissions and deaths by age. Scenarios shown here assume: no waning immunity; 1.8-fold increased severity of Delta relative to Alpha; central vaccine effectiveness assumptions against Delta B.1.617.2 (Table 3); medium changes in mobility following implementation of roadmap Step 4 on the 19th of July 2021; and a 40% reduction in personal protective measures.

Supplementary material

Table S1 - Vaccine effectiveness against pre-B.1.1.7 and B.1.1.7 relevant evidence (updated 1st July 2021)

Description	Relevant evidence, assumed value shown in bold
Overall protection against infection for AstraZeneca dose 1	Shrotri et al. results, secondary analyses, paragraph 1, p.8 adjusted hazard ratio 0.33 (0.16, 0.68) at 28-34 days post vaccination. Pritchard et al. supplementary Table 7, adjusted odds ratio >=21 days after first dose of AZ 0.36 (0.3, 0.45). **0.67 (+28 days)**
Overall protection against disease for AstraZeneca dose 1	Lopez Bernal et al. Table 3, ChAdOx1 adjusted odds ratio d1:28-34 0.4 (0.27-0.59), adjusting 0.6 up to equivalent estimate for protection against infection (see cell above) **0.67 (+28 days) as for infection**
Overall protection against hospitalisation for AstraZeneca dose 1	Vasileiou et al. Table 2, vaccine programme effect for ChAdOx1 21-27 days post first vaccine is 81% (72 to 87%), 28-34 days post first vaccine is 88% (75-94%), 35-41 days post first vaccine is 97% (63-100%). Smaller numbers. Table 3 splits analysis into age groups for ChAdOx1: 65-79 years 21-27 days post first dose 68% (31 to 85%), 80+ years 21-27 days post first dose 77% (63 to 86%) and 28-34 days post first dose 81% (60 to 91%). Small numbers for 65-79 years old and for 18-64 years old, so difficult to directly compare but overall the vaccine effect appears stronger in the younger (65-79 years) cohort than the older (80+) cohort, for the first three time points which enable comparison. Effect reversed for fourth time point. Ismail et al. estimate vaccine effectiveness against hospitalisation of 73% (60-81%) for 80+ year olds and 84% (74-89%) for 70-79 year olds, 28 days following the first dose of AZ. When analysis is not split across vaccine products, the same study estimates efficacy against hospitalisation of 80% (74-85%) for 80+ year olds and 82% (75-87%) for 70-79 year olds. **0.845 (+28 days)**
Overall protection against mortality for AstraZeneca dose 1	Lopez Bernal et al. B estimated a hazard ratio of 0.45 (0.34 - 0.59) for cases vaccinated with one dose of AZ compared to unvaccinated cases, indicating an additional 55% (41-66%) protection against death given becoming a case for individuals vaccinated with one dose of AZ. Using the aforementioned estimate of a 55% increase and assuming this in addition to protection against disease of **0.67,** we get overall protection

	against mortality of 0.8515 **0.845 (+28 days)**
Overall protection against onward transmission for AstraZeneca dose 1	Harris et al. calculate an adjusted odds ratio of being a secondary case within a household of index cases vaccinated with ChAdOx1 (AstraZeneca) at least 21 days before testing positive as 0.52 (0.43-0.62) and index cases vaccinated with BNT162b2 (Pfizer-BioNTech) at least 21 days before testing positive as 0.54 (0.47-0.62). **0.47 (+28 days)**
Overall protection against infection for AstraZeneca dose 2	Shrotri et al. results, secondary analyses, paragraph 1, p.8 adjusted hazard ratio 0.32 (0.15, 0.66) at 35-48 days post vaccination **0.68 (+14 days)**
Overall protection against disease for AstraZeneca dose 2	Voysey et al. A randomised controlled trial for ChAdOx1 nCoV-19 vaccine AZD1222, Table 3, average of efficacies more than 14 days after a second dose for LD/SD and SD/SD in 'COV002 (UK), age 18–55 years with >8 weeks' interval between vaccine doses*' row -> 0.778 = (0.9+0.656)/2 **0.78 (+14 days)**
Overall protection against hospitalisation for AstraZeneca dose 2	Ismail et al. estimate vaccine effectiveness against hospitalisation of 92% (87-95%) 14 days after a second dose across both AZ and Pfizer vaccines **0.9 (+14 days)**
Overall protection against mortality for AstraZeneca dose 2	**0.95 (+14 days)**
Overall protection against onward transmission for AstraZeneca dose 2	**0.57 (+14 days)**
Overall protection against infection for Pfizer dose 1	Hall et al. Table 2, full cohort adjusted hazard ratio d1>=21 days 0.30 (0.15-0.45). Pritchard et al. supplementary Table 7, adjusted odds ratio >=21 days after first dose of Pfizer 0.33 (0.28, 0.39) **0.7 (+28 days)**
Overall protection against disease for Pfizer dose 1	Lopez Bernal et al. Table 2, odds ratio vs day 4-9, d1:28-34 0.30 (0.22-0.41)

	0.7 (+28 days)
Overall protection against hospitalisation for Pfizer dose 1	Hyams et al. Table 2, adjusted vaccine effectiveness for one dose of BNT162b2 71.4% (43.1 - 86.2%). When the analysis of the effectiveness of one dose of BNT162b2 was restricted to the period covered by the ChAdOx1nCoV-19 analysis after the end of 2020, the observed adjusted estimate was 79.3% (95% CI 47.0-92.5) (P=0.0014). Dagan et al. estimate vaccine effectiveness against hospitalisation of 74% (56–86%) 14-20 days after first dose and 78% (61–91%) 21 to 27 days after first dose. Vasileiou et al. Table 2, vaccine effect for BNT162b2 21-27 days post first vaccine is 78% (71 to 83) and 28-34 days post first vaccine is 91% (85 to 94). Estimated vaccine effect against hospitalisation is reduced for later time points to 78% and 77%. Ismail et al. estimate vaccine effectiveness against hospitalisation of 81% (76-85%) for 80+ year olds and 81% (73-87%) for 70-79 year olds, 28 days following the first dose of Pfizer. When the analysis is not split across vaccine products, the same study estimates protection against hospitalisation of 80% (74-85%) for 80+ year olds and 82% (75-87%) for 70-79 year olds, 28 days following the first vaccine dose **0.845 (+28 days)**
Overall protection against mortality for Pfizer dose 1	Dagan et al. estimate vaccine effectiveness against mortality of 72% (19–100%) 14-20 days after first dose and 84% (44–100%) 21 to 27 days after first dose. Lopez Bernal et al. B estimated a hazard ratio of 0.56 (0.47 - 0.68) for cases vaccinated with one dose of Pfizer compared to unvaccinated cases, indicating an additional 44% (32-53%) protection against death given becoming a case for individuals vaccinated with one dose of Pfizer. Using the aforementioned estimate of a 44% increase and assuming this in addition to protection against disease of **0.7,** we get overall protection against mortality of 0.832 **0.845 (+28 days)**
Overall protection against onward transmission for Pfizer dose 1	Harris et al. calculate an adjusted odds ratio of being a secondary case within a household of index cases vaccinated with ChAdOx1 (AstraZeneca) at least 21 days before testing positive as 0.52 (0.43-0.62) and index cases vaccinated with BNT162b2 (Pfizer-BioNTech) at least 21 days before testing positive as 0.54 (0.47-0.62). **0.47 (+28 days)**
Overall protection against	Hall et al. Table 2, full cohort adjusted hazard ratio d2>=7 days

infection for Pfizer dose 2	0.15 (0.04-0.26). Pritchard et al. supplementary Table 7, adjusted odds ratio post second dose of Pfizer 0.28 (0.21, 0.36). Haas et al. estimate vaccine protection against SARS-CoV-2 infection (both asymptomatic and symptomatic and symptoms unknown) of 95.3% (94.9-95.7%) **0.85 (+14 days)**
Overall protection against disease for Pfizer dose 2	Lopez Bernal et al. Table 2, odds ratio vs day 4-9, d2:14+ 0.11 (0.07-0.15). Haas et al. estimate vaccine protection against symptomatic COVID-19 >7 days after second dose of 97% (96.7-97.2%) **0.89 (+14 days)**
Overall protection against hospitalisation for Pfizer dose 2	Dagan et al. estimate vaccine effectiveness against hospitalisation of 87% (55–100%) >7 days after second dose. Haas et al. estimate vaccine protection against COVID-19 related hospitalisation >7 days after second dose of 97.2% (96.8-97.5%). Ismail et al. estimates vaccine protection against hospitalisation of 93% (89-95%) for individuals aged 80+ years 14 days after receiving their second dose of Pfizer. When the analysis is not split by vaccine type, the same study estimates protection against hospitalisation of 92% (87-95%) for 80+ year olds 14 days after second dose **0.9 (+14 days)**
Overall protection against mortality for Pfizer dose 2	Dagan et al. estimate vaccine effectiveness against mortality of 72% (19–100%) 14-20 days after first dose and 84% (44–100%) 21 to 27 days after first dose. Haas et al. estimate vaccine protection against death >7 days after second dose of **96.7%** (96.0-97.3%). Lopez Bernal et al. B estimated a hazard ratio of 0.31 (0.14 - 0.69) for cases vaccinated with two doses of Pfizer compared to unvaccinated cases, indicating an additional 69% (31-86%) protection against death given becoming a case for individuals vaccinated with two doses of Pfizer. Using the aforementioned estimate of a 69% increase and assuming this in addition to protection against disease of 0.89, we get overall protection against mortality of **0.9659** **0.95 (+14 days)**
Overall protection against onward transmission for Pfizer dose 2	**0.57 (+14 days)**