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Coronavirus (COVID-19): Analysis

Coronavirus (COVID-19): modelling the epidemic in Scotland (Issue No. 47)

Background

This is a report on the Scottish Government modelling of the spread and level of Covid-19. This updates the previous publication on modelling of Covid-19 in Scotland published on 8 April 2021. The estimates in this document help the Scottish Government, the health service and the wider public sector plan and put in place what is needed to keep us safe and treat people who have the virus.

This edition of the research findings focuses on the epidemic as a whole, looking at estimates of R, growth rate and incidence as well as local measures of change in the epidemic.

Key Points

- The reproduction rate R in Scotland is currently estimated as being between 0.8 and 1.0.
- The number of new daily infections for Scotland is estimated as being between 4 and 28, per 100,000 people. This is a decrease from last week.
- The growth rate for Scotland is currently estimated as being between -4% and 0%.
- Modelling on which local authority areas are exceeding what would be expected in terms of Covid-19 infections in the last seven days has recommenced, as we are below 50 cases per 100,000 people at the national level. This shows that there are currently no local authority areas exceeding what we would expect over the last seven days.
- Average contacts are still higher than seen during the lockdown period (averaging around 3 daily contacts) but have decreased slightly in the last two weeks, with a current level of 3.5 daily contacts.
- Contacts within the work and school setting have shown a decrease in the last two weeks by 25% and 36% respectively, coinciding with spring holidays that commenced from 26th March.

- Mean contacts in the home setting have increased by approximately 16% over the same period.
- Those aged under 50 have shown a decrease in overall contacts whereas those aged 50 and over have increased their contacts
- The 30-49 age group has reported a decrease in contacts within the school and work place. This coincides with a decrease shown in the interactions between this age group and individuals under 18.
- The number of participants visiting different locations has remained at a similar level since January with the exception of those who have visited another's home, increasing from 21% in January to 38% in the most recent survey.
- Although the older population have increased their contacts in the last two weeks, daily cases and deaths have declined over the same period.
- Hospital bed and ICU occupancy are projected to fall over the next few weeks, but these both may plateau or increase as a result of schools reopening and other relaxations of non-pharmaceutical interventions.
- Modelled rates per 100K indicate that for the week commencing 25 April 2021, no local authorities have at least a 75% probability of exceeding 50 cases. In last week's issue of these Research Findings, 4 local authorities had a 75% or higher probability of exceeding 50 cases per 100K.
- The overall level of wastewater Covid-19 this week was similar to last week, consistent with a slow decline in the rate of new cases.

Overview of Scottish Government Modelling

Epidemiology is the study of how diseases spread within populations. One way we do this is using our best understanding of the way the infection is passed on and how it affects people who catch it to create mathematical simulations. Because people who catch Covid-19 have a relatively long period in which they can pass it on to others before they begin to have symptoms, and the majority of people infected with the virus will experience mild symptoms, this "epidemiological modelling" provides insights into the epidemic that cannot easily be measured through testing e.g. of those with symptoms, as it estimates the total number of new daily infections and infectious people, including those who are asymptomatic or have mild symptoms.

Modelling also allows us to make short-term forecasts of what may happen with a degree of uncertainty. These can be used in health care

and other planning. The modelling in this research findings is undertaken using different types of data which going forward aims to both model the progress of the epidemic in Scotland and provide early indications of where any changes are taking place.

Modelling outputs are provided here on the current epidemic in Scotland as a whole, based on a range of methods. Because it takes a little over three weeks on average for a person who catches Covid-19 to show symptoms, become sick, and either die or recover, there is a time lag in what our model can tell us about any re-emergence of the epidemic and where in Scotland this might occur. However modelling of Covid-19 deaths is an important measure of where Scotland lies in its epidemic as a whole. In addition, the modelling groups which feed into the SAGE consensus use a range of other data along with deaths in their estimates of R and the growth rate. These outputs are provided in this research findings. The type of data used in each model to estimate R is highlighted in Figure 1.

We use the Scottish Contact Survey (SCS) to inform a modelling technique based on the number of contacts between people. Over time, a greater proportion of the population will be vaccinated. This is likely to impact contact patterns and will become a greater part of the analysis going forwards.

The delivery of the vaccination programme will offer protection against severe disease and death. The modelling includes assumptions about compliance with restrictions and vaccine take-up. Work is still ongoing to understand how many vaccinated people might still spread the virus if infected. As Covid-19 is a new disease there remain uncertainties associated with vaccine effectiveness. Furthermore, there is a risk that new variants emerge for which immunisation is less effective.

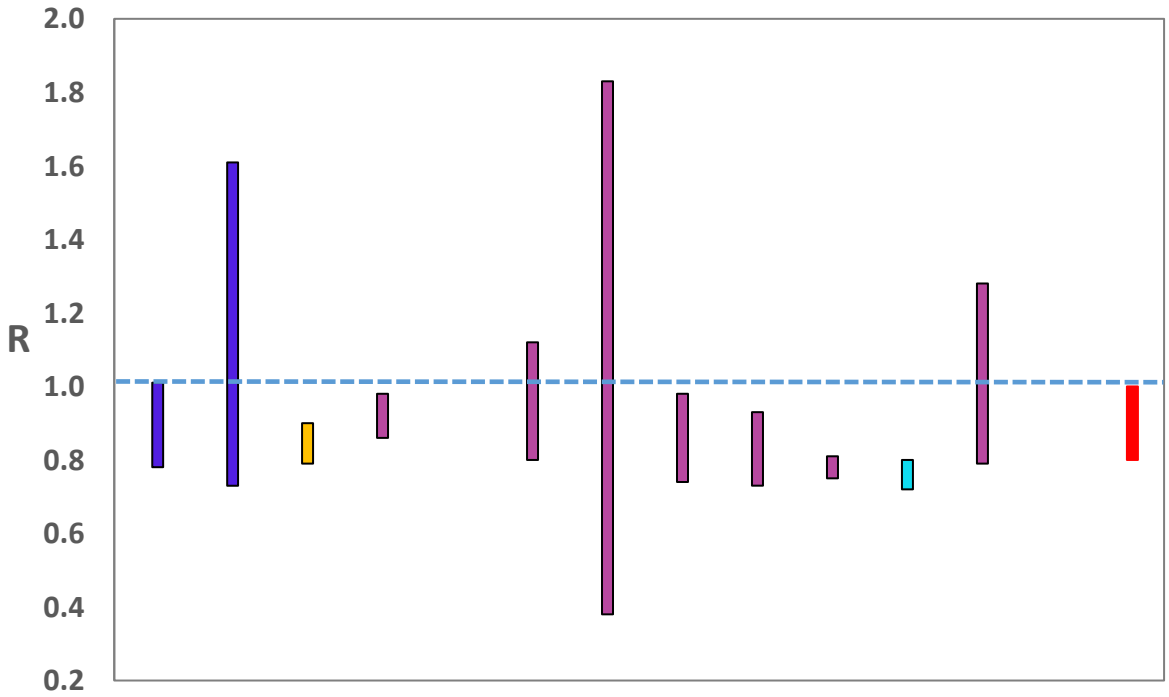
The logistical model utilises results from the epidemiological modelling, principally the number of new infections. The results are split down by age group, and the model is used to give a projection of the number of people that will go to hospital, and potentially to ICU. This will continue to be based on both what we know about how different age groups are effected by the disease and the vaccination rate for those groups.

What the modelling tells us about the epidemic as a whole

The various groups which report to the Scientific Pandemic Influenza Group on Modelling (SPI-M) use different sources of data in their models

(i.e. deaths, hospital admissions, cases) so their estimates of R are also based on these different methods. SAGE's consensus view across these methods, as of 14 April, was that the value of R in Scotland was between 0.8 and 1.0 (see Figure 1). This is unchanged from the estimate of R as of 7 April. Particular care should be taken when interpreting these estimates as they are based on low numbers of cases and deaths, and so should not be treated as robust enough to inform policy decisions alone.

Figure 1. Estimates of R_t for Scotland, as of 14 April, including 90% confidence intervals, produced by SAGE. The blue bars are death-based models, purple use multiple sources of data and cyan uses Covid-19 test results. The estimate produced by the Scottish Government is the third from left (yellow), while the SAGE consensus range is the right-most (red).

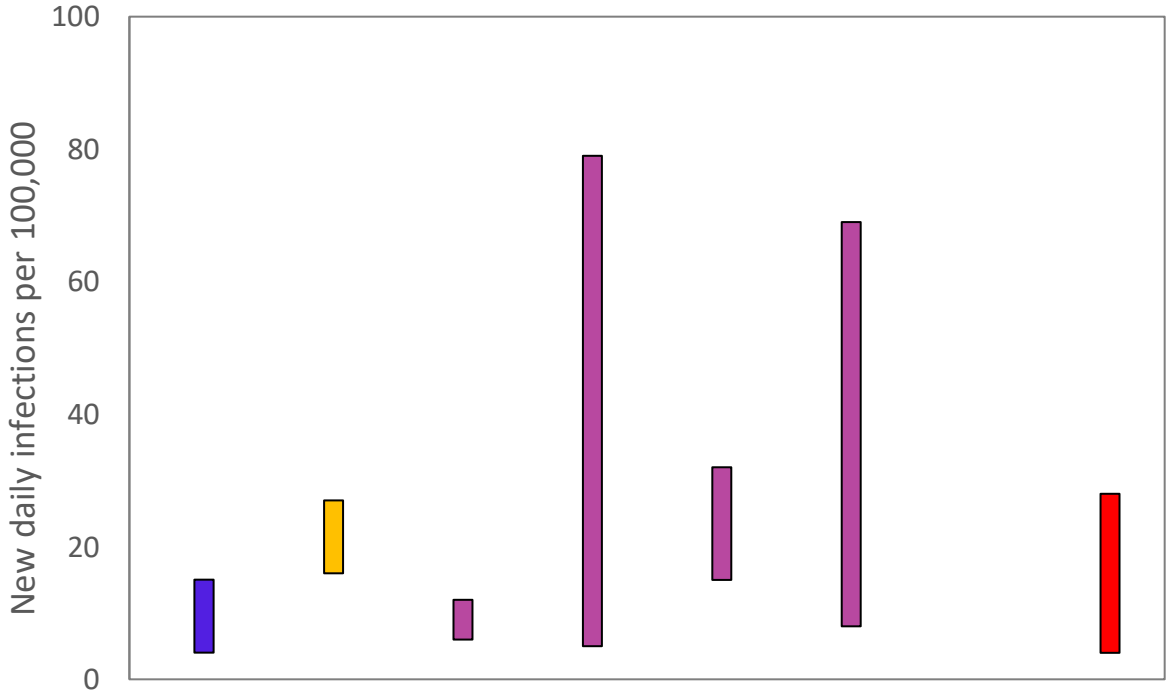


Source: Scientific Advisory Group for Emergencies (SAGE).

The various groups which report to the Scientific Pandemic Influenza Group on Modelling (SPI-M) use different sources of data in their models to produce estimates of incidence (Figure 2). The Scottish Government results this week have been computed using a platform called Epidemia (see Technical Annex in issue 37) which expands the Bayesian semi-mechanistic model which the Scottish Government runs. SPI-M's consensus view across these methods, as of 14 April, was that the incidence of new daily infections in Scotland was between 4 and 28 new infections per 100,000. This is a decrease since last week's estimate.

This equates to between 200 and 1,500 people becoming infected each day in Scotland.

Figure 2. Estimates of incidence for Scotland, as of 14 April, including 90% confidence intervals, produced by SPI-M. The blue bar is a death-based model and the purple bars represent models which use multiple sources of data. The estimate produced by the Scottish Government (a semi-mechanistic model) is the second from left (yellow), while the SAGE consensus range is the right-most (red).



Source: Scientific Pandemic Influenza Group on Modelling (SPI-M).

The consensus from SAGE for this week is that the growth rate in Scotland is between -4% and 0% per day. This is unchanged from the estimate as at 7 April.

What we know about how people's contact patterns have changed

Average contacts are still higher than seen during the lockdown period (averaging around 3 daily contacts) but have decreased slightly in the last two weeks, with a current level of 3.5 daily contacts as seen in Figure 3. Contacts within the work and school setting have shown a decrease in the last two weeks by 25% and 36% respectively, coinciding with spring holidays that commenced from 26th March. In contrast, mean contacts in the home setting have increased by approximately 16% over the same period.

Figure 3. Mean Adult Contacts (truncated at 100) from SCS.

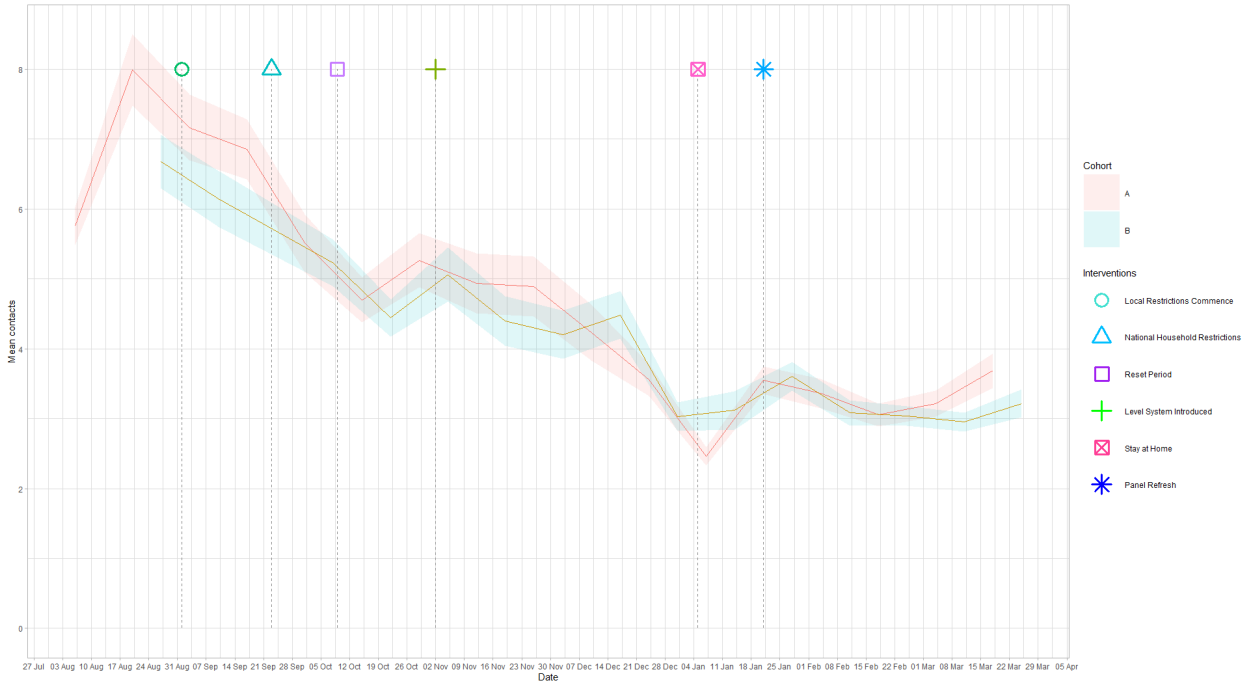
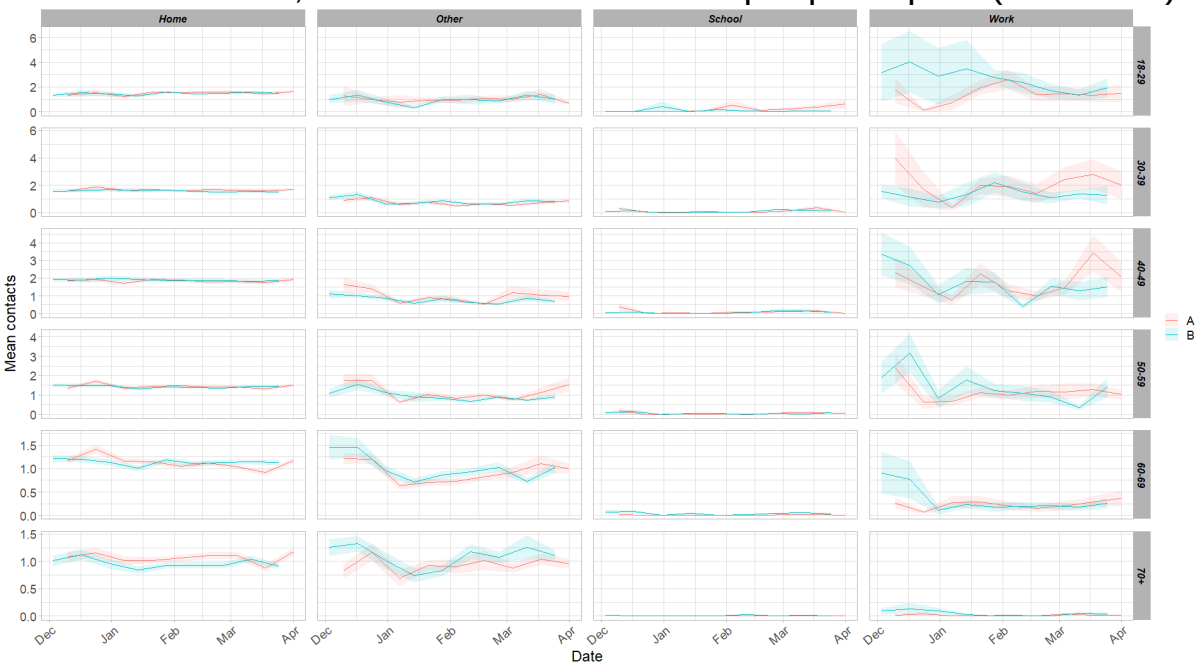


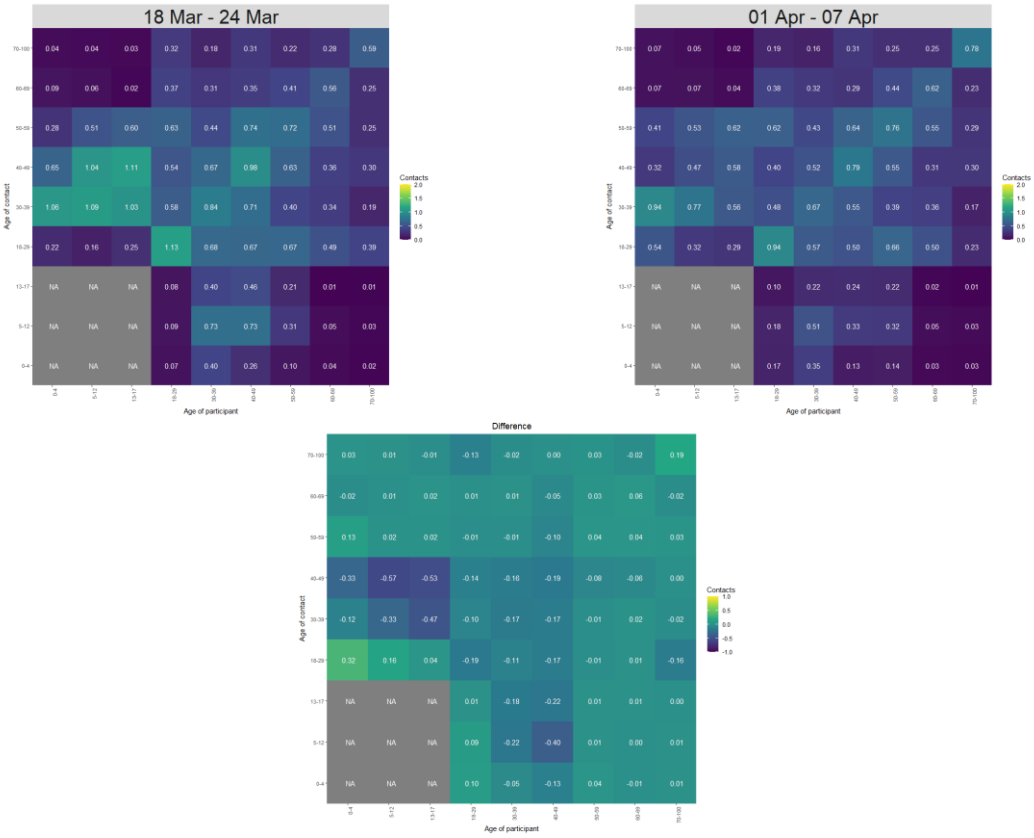
Figure 4 shows how contacts change across age group and setting. Those aged under 50 have shown a decrease in overall contacts whereas those aged 50 and over have increased their contacts in the most recent survey. The increase in contacts for the older age cohorts is driven largely by increased contacts within the home setting while the overall decrease for those aged between 30 and 49 is influenced by a reduction in contacts within the work and school setting.

Figure 4. Average (mean) contacts for each panel per day by setting for adults in Scotland, truncated to 100 contacts per participant (from SCS).



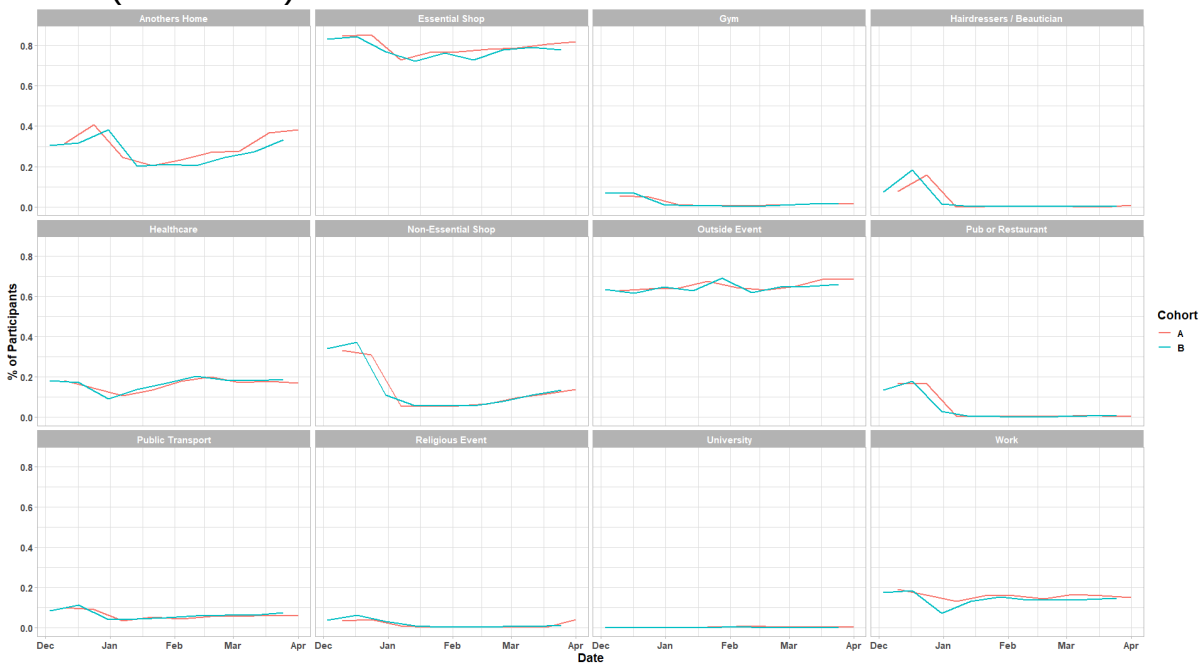
The heatmaps in Figure 5 show the mean overall contacts between age groups for the weeks relating to 18th – 24th March and 1st –7th April, and the difference between these periods. As shown above, the 30-49 age group has reported a decrease in contacts within the school and work place. This coincides with a decrease shown in interactions between this age group and individuals under 18. Those aged 18-29 have shown the biggest increase in interactions with those aged under 5. Interactions between other age groups remain similar to those reported two weeks prior.

Figure 5. Overall mean contacts by age group for the weeks relating to 11th – 17th March and 25th – 31st March.



As Figure 6 shows, the number of participants visiting different locations has remained at a similar level with the exception of those who have visited another's home. This has increased from 20% at the end of January to 38% in the most recent survey.

Figure 6. Locations visited by participants at least once for panel A and B (from SCS).



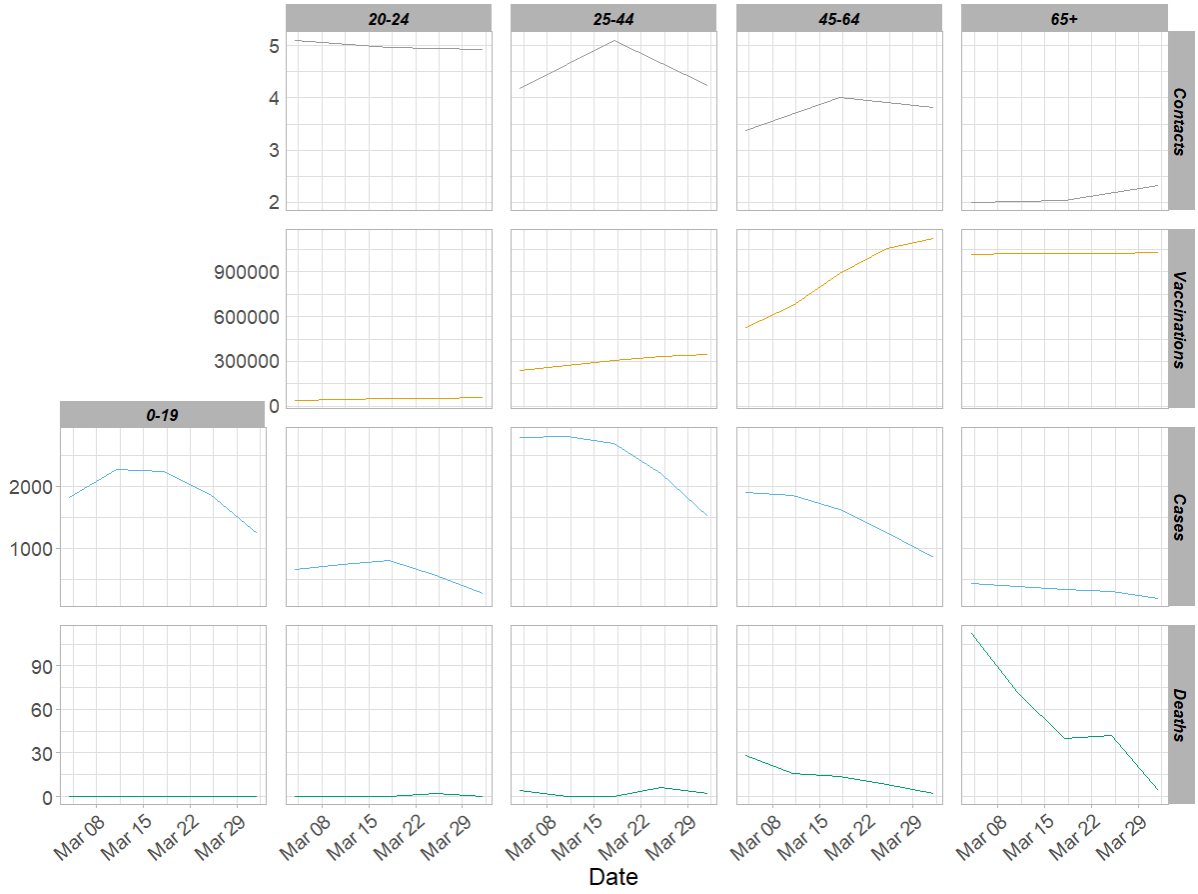
Vaccinations and contacts patterns

The vaccinations programme commenced in Scotland from December 2020. This section looks at the contact patterns of those who have been vaccinated against those who have not.

There continues to be no significant difference in contacts between the vaccinated and unvaccinated within either the 50-54 or 55-59 age group (once healthcare professionals, who were vaccinated earlier as a priority group, were removed).

From Figure 7, it can be seen that where contacts have remained consistent or even increased for the older age groups, cases and deaths have decreased. This coincides with the increasing number of vaccinations supplied to the population. As mentioned above, in the last two weeks, contacts for the oldest population have increased while there are decreases within daily case and death numbers.

Figure 7. Average contacts for Panel A, daily cases and deaths[1] and cumulative vaccinations by age band[2]



What the modelling tells us about estimated infections as well as Hospital and ICU bed demand

The Scottish Government assesses the impact of Covid-19 on the NHS in the next few weeks in terms of estimated number of infections. For more on how we do this see page 4 of Issue 1 of the Research Findings[3]. Figure 8 shows two projections[4] which take account of compliance and behaviour (better and worse[5]).

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[1] Deaths and Cases from PHS COVID-19 daily cases in Scotland dashboard

[2] Vaccination and contact data for the 0-19 age cohort is not presented due to the vast majority of the age group not being offered vaccinations and the SCS excluding contacts between children.

[3] Coronavirus (COVID-19): modelling the epidemic - gov.scot (www.gov.scot)

[4] Four week projections are included here.

[5] Both scenarios are based on current vaccine roll-out plans and efficacy assumptions. The difference between the two projections reflects uncertainty about behaviour and compliance as interventions are relaxed.

Figure 8. Medium term projections of modelled total new infections, adjusting positive tests[6] to account for asymptomatic and undetected infections, from Scottish Government modelling, positive test data up to 10 April.

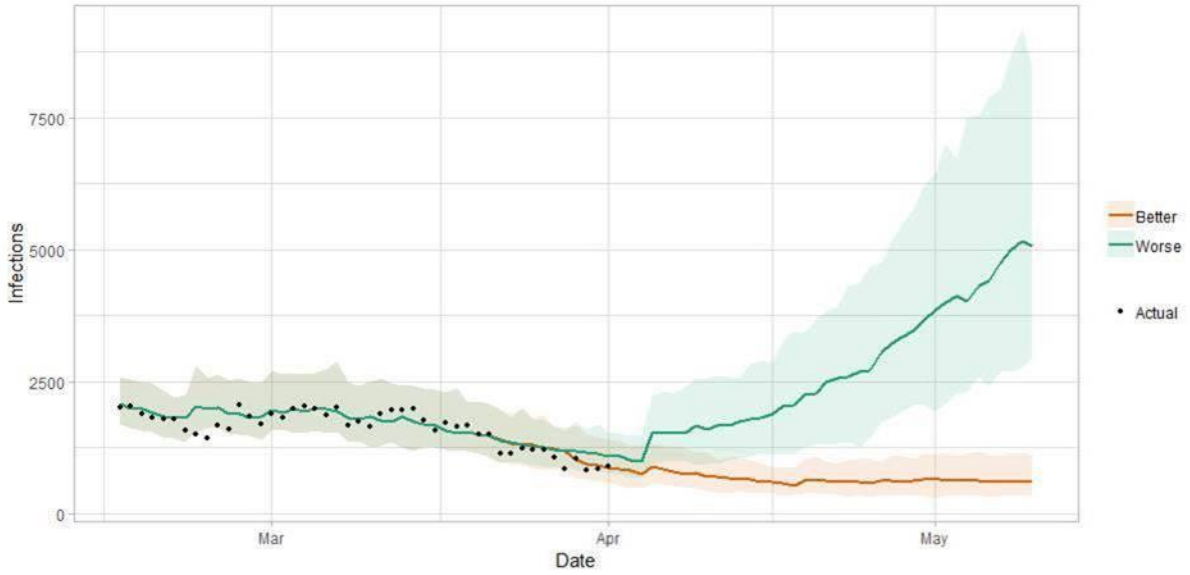


Figure 9 shows the impact of the projections on the number of people in hospital. The modelling includes all hospital stays, whereas the actuals only include stays up to 28 days duration which are linked to Covid-19. Work is ongoing to show the modelled occupancy for stays up to a 28 day limit.

[6] The actual positive tests are adjusted to coincide with the estimated day of infection.

Figure 9. Medium term projections of modelled hospital bed demand, from Scottish Government modelling.

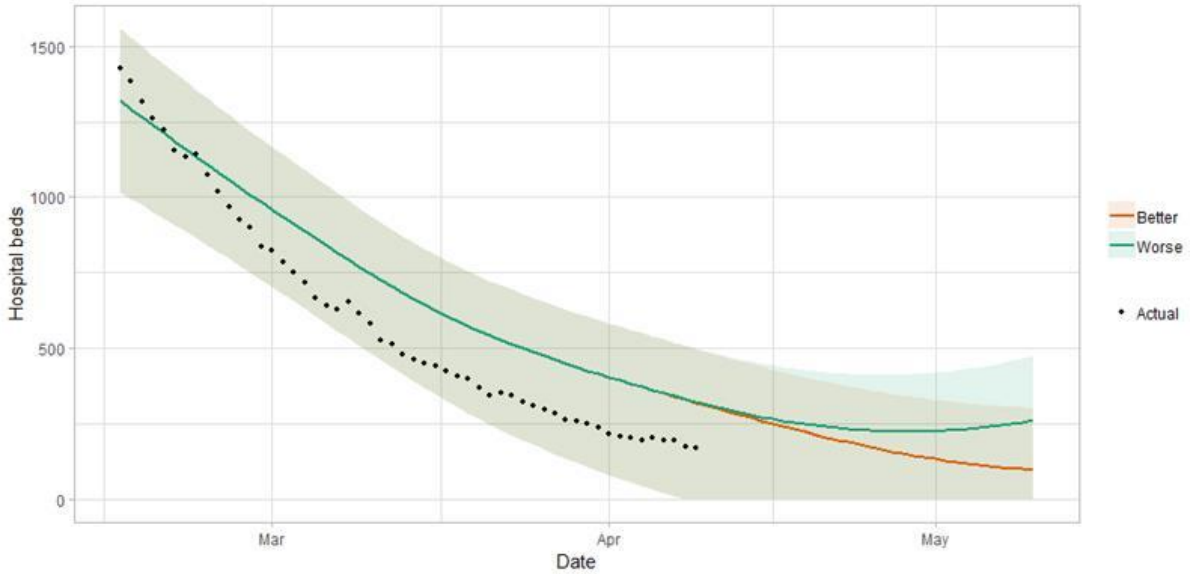
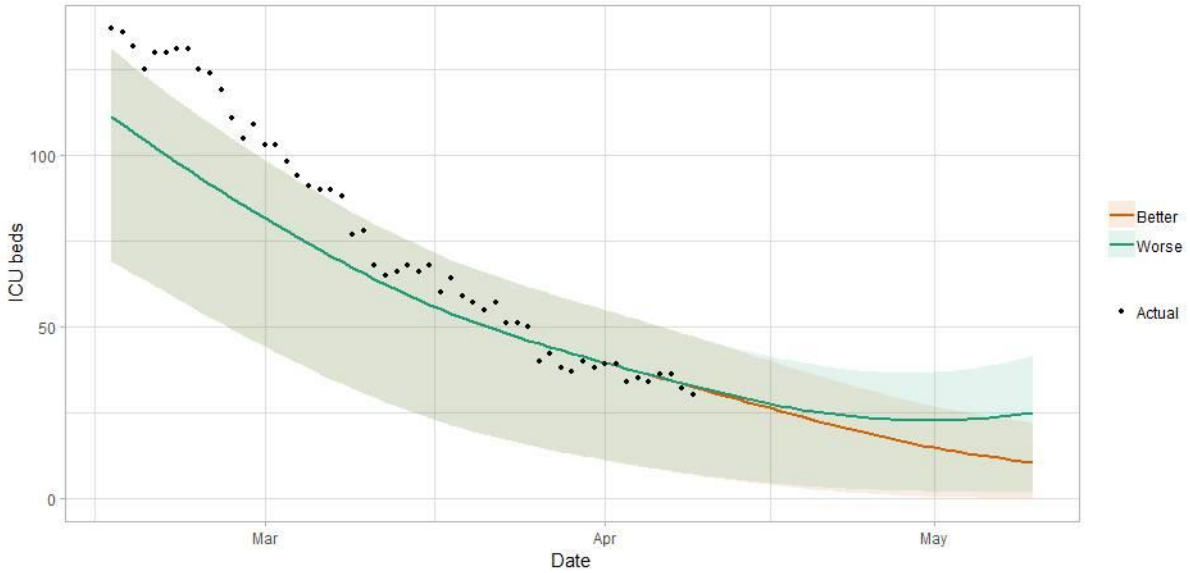


Figure 10 shows the impact of the projection on ICU bed demand.

Figure 10. Medium term projections of modelled ICU bed demand, from Scottish Government modelling[7].



A comparison of the actual data against historical projections is included in the Technical Annex.

[7] Actual data does not include full numbers of CPAP. ICU bed actuals include all ICU patients being treated for Covid-19 including those over 28 days.

What the modelling tells us about projections of hospitalisations and deaths in the medium term

SAGE produces projections of the epidemic[8] (Figures 11 and 12), combining estimates from several independent models (including the Scottish Government's logistics modelling, as shown in Figures 9-10). These projections are not forecasts or predictions. They represent a scenario in which the trajectory of the epidemic continues to follow the trends that were seen in the data up to 12 April.

Disruption to data flows and increased reporting delays over the Easter period makes it difficult to interpret recent trends in the data. This means the current state of the epidemic may not yet be fully reflected in the epidemiological data used to produce these projections.

Modelling groups have used data from contact surveys, previous findings[9] and their own expert judgement to incorporate the impact of re-opening schools and the Easter holidays on transmission. **The projections do not include the effects of any other future policy or behavioural changes.**

The delay between infection, developing symptoms, the need for hospital care, and death means they will not fully reflect the impact of behaviour changes in the two to three weeks prior to 12 April. Projecting forwards is difficult when the numbers of cases, admissions and deaths fall to very low levels, which can result in wider credible intervals reflecting greater uncertainty.

These projections include the potential impact of vaccinations over the next four weeks. Modelling groups have used their expert judgement and evidence from Public Health England, Scottish universities, Public Health Scotland and other published efficacy studies when making assumptions about vaccine effectiveness.

Beyond two weeks, the projections become more uncertain with greater variability between individual models. This reflects the large differences that can result from fitting models to different data streams, and the influence of small deviations in estimated growth rates and current incidence.

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[8] Four week projections are provided here Scientific evidence supporting the government response to coronavirus (COVID-19) - GOV.UK (www.gov.uk)

[9] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/963359/S1072_SPI-M-O_Statement_on_relaxation_of_NPI_scenarios__schools_.pdf

Figure 11. SAGE medium-term projection of daily hospitalisations in Scotland, including 50% and 90% credible intervals.

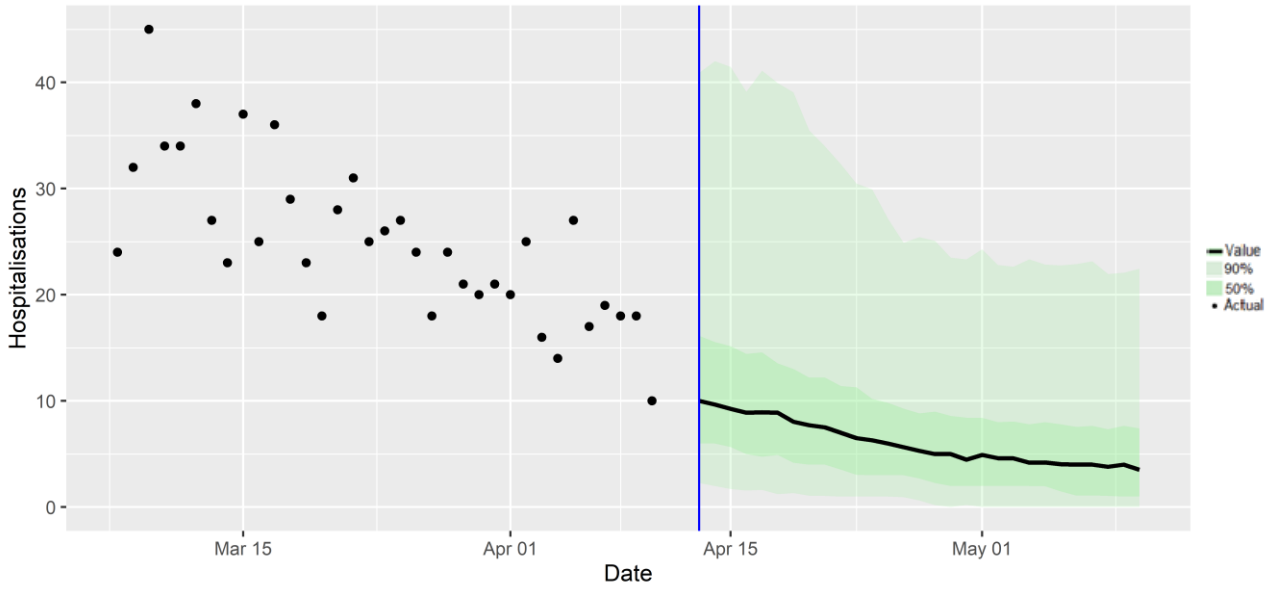
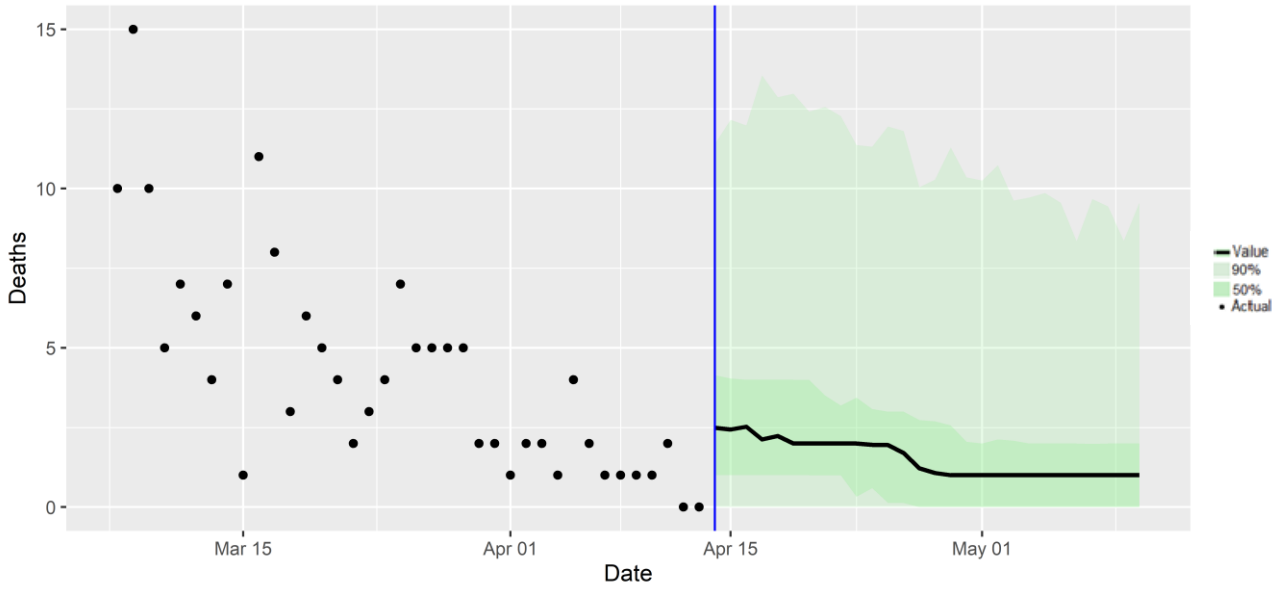


Figure 12. SAGE medium-term projection of daily deaths[10] in Scotland, including 50% and 90% credible intervals.



[10] PHS defines a confirmed COVID-19 death as an individual who dies within 28 days of their first positive COVID-19 laboratory report.

What the modelling tells us about whether Covid-19 infections exceeded what would be expected at this stage in the epidemic

Whilst metrics such as the R number, growth rate and incidence have helped us understand the spread of Covid-19 for the whole of Scotland, since October 2020 we have supplemented this with forecasts at local authority level to understand which areas include hotspots.

Recently the number of cases has dropped below 50 per 100,000 people, so we are able to recommence modelling “exceedance” which we stopped in September 2020 (Issue 17) as we entered the resurgence of the virus over the autumn and winter. Exceedance indicates whether the number of confirmed infections (based on testing) in each local authority area exceeds the number that was expected (see the Technical Annex for more information on exceedance).

An analysis of trends across Local Authorities in Scotland has been developed by modellers at the University of Warwick on behalf of the Scottish Government. Numbers of positive tests recorded each day, adjusted for population of each local authority and number of cases seen in preceding weeks, should fall within a certain distribution of values, which will rise and fall depending on the number of cases being seen nationally. Areas where the number of positive test results fall beyond the upper 95th percentile of this distribution may be at risk of seeing increased local transmission of Covid and heightened vigilance may be required. This happens when the cumulative exceedance is higher than 6.0. No local authorities have experienced a significant cumulative exceedance in the last week as a result of national background levels.

Figure 13 shows that there are currently no local authority areas exceeding the number of cases that we would expect over the last seven days given the phase of the epidemic.

Figure 13. Map of cumulative weekly exceedance to 12 April, for Scottish Local Authorities

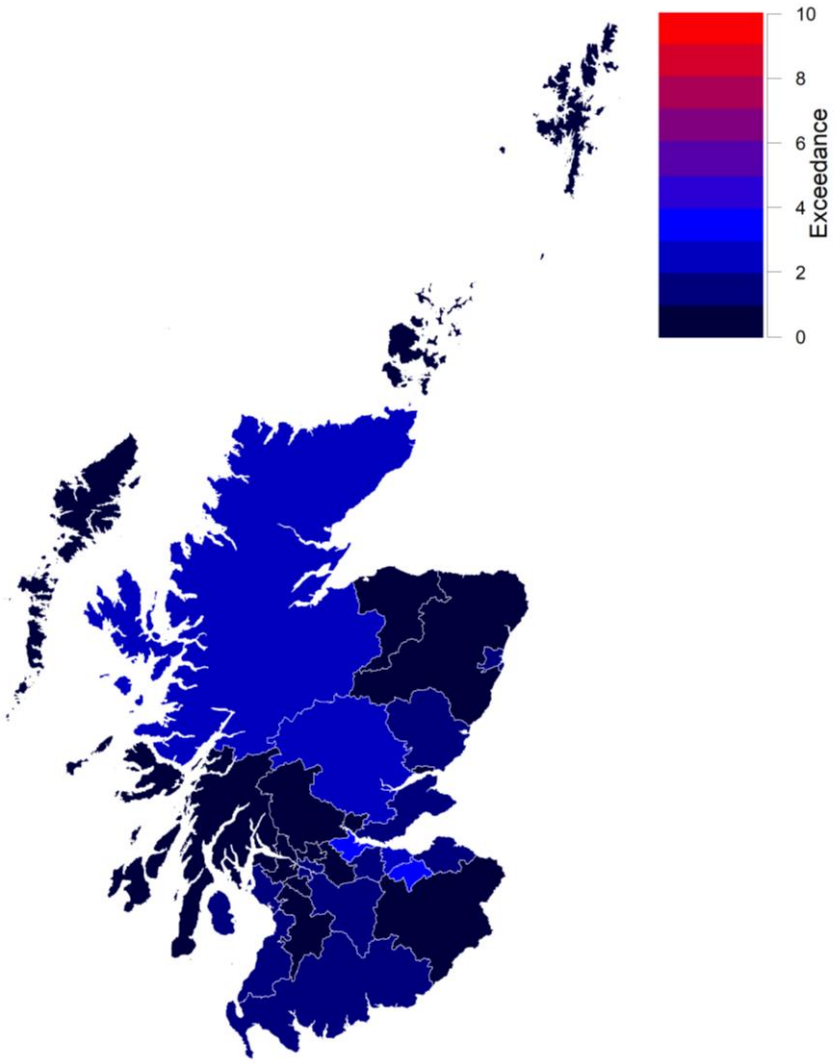
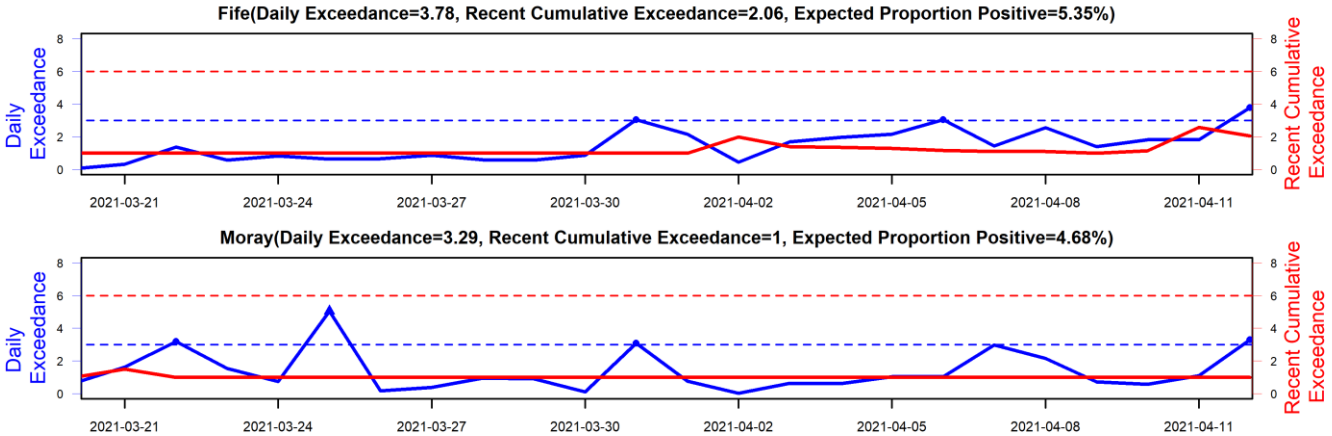


Figure 14. Graphs of daily and cumulative exceedance for the local authorities deemed as higher risk over the period 06 – 12 April



What we know about which local authorities are likely to experience high levels of Covid-19 in two weeks' time

We are using modelling based on Covid-19 cases and deaths from several academic groups to give us an indication of whether a local authority is likely to experience high levels of Covid-19 in the future. This has been compiled via SPI-M into a consensus. In this an area is defined as a hotspot if the two week prediction of cases (positive tests) per 100K population are predicted to exceed a threshold, e.g. 500 cases.

Modelled rates per 100K (Figure 15) indicate that for the week commencing 25 April 2021, no local authorities have at least a 75% probability of exceeding 50 cases. In last week's issue of these Research Findings, 4 local authorities had a 75% or higher probability of exceeding 50 cases per 100K. Please note that the local estimates should be interpreted with caution as they are based on fewer models than previous reports.

Figure 15. Probability of local authority areas having more than 50, 100, 300 or 500 cases per 100K (25 April – 1 May 2021).

What can analysis of wastewater samples tell us about local outbreaks of Covid-19 infection?

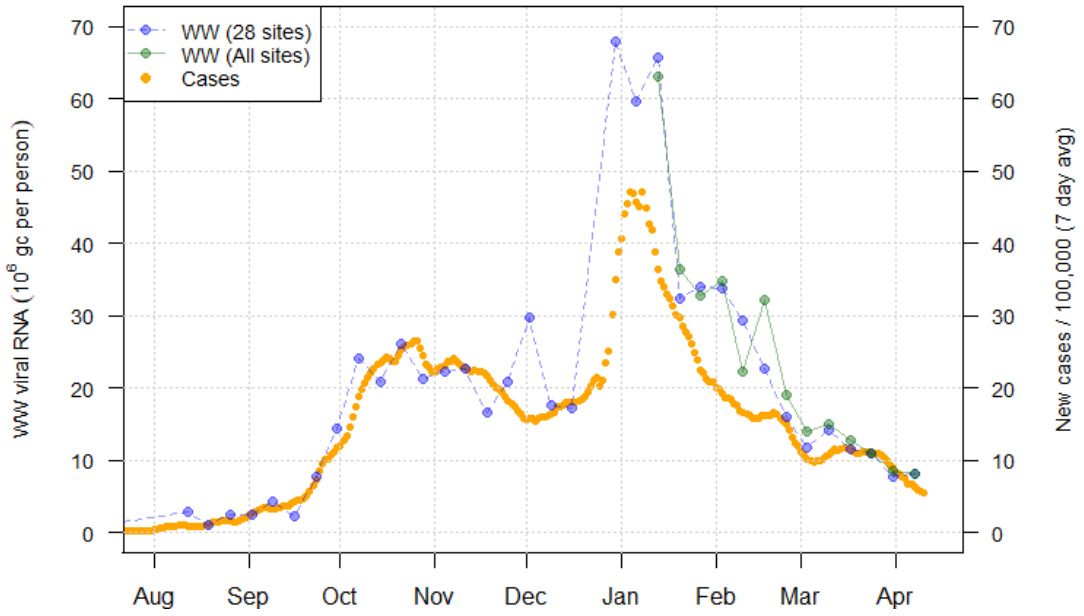
Levels of Covid-19 in wastewater collected at 97 sites around Scotland are adjusted for population (and local changes in intake flow rate) and compared to daily 7-day average positive case rates derived from Local

Authority and Neighbourhood (Intermediate Zone) level aggregate data. See Technical Annex in Issue 34 of these Research Findings for the methodology.

The overall level of wastewater Covid-19 this week was similar to last week, consistent with a slow decline in the rate of new cases.

We show in Figure 16 the national aggregate for the original 28 sites with long-term records. This also shows in green the aggregate for the full set of 97 currently sampled sites. The expansion of sites that are sampled began in January and now covers 82% of the population (4.1 million). In both cases, we exclude an anomalous February reading from Seafield, Edinburgh – see Issue 40 for details. Both sets of sites give very similar WW RNA readings this week, showing little change from levels last week.

Figure 16. National average trends in wastewater Covid-19 and daily case rates (7 day moving average) with the original 28 sites and all 97 current sites. An anomalously high reading at Seafield is removed. See Issue 40 for details.

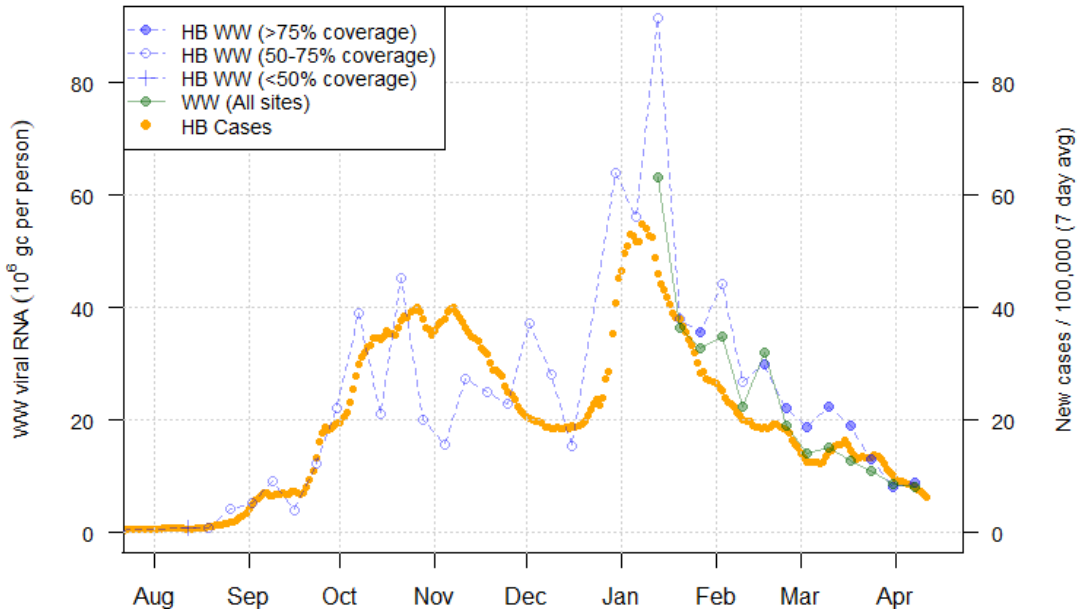


The sampled wastewater sites belong to 14 different health boards. We may compute population weighted averages using only sites belonging to each of the health boards and compare to the health board case rates and the Scottish all sites average. This is done for NHS Greater Glasgow and Clyde, NHS Borders, and NHS Forth Valley respectively in Figures 17-19 below.

Because different health boards can have different numbers of sites, and the number of sites change over time, we also show the ‘coverage’ on

these graphs, defined as the proportion of the total population of each health board represented by the catchments within it. Note that we will in future revise these graphs to take into better account catchments overlapping multiple health boards.

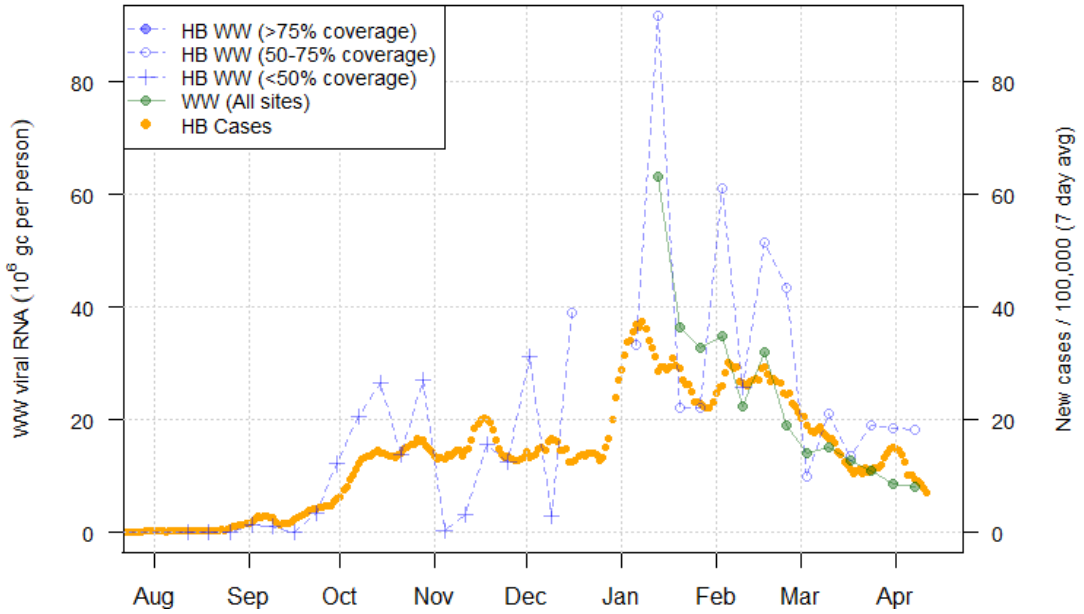
Figure 17. Average trends in wastewater Covid-19 and daily case rates (7 day moving average) in the Greater Glasgow and Clyde Health Board (pop: 1183 k).



NHS Greater Glasgow and Clyde (Figure 17) is a large health board and includes some of the larger sampled sites (9 sites with mean population of 116k). In terms of its wastewater Covid-19 characteristics and case history, it is very similar to the Scottish average, showing a slow decline in recent times.

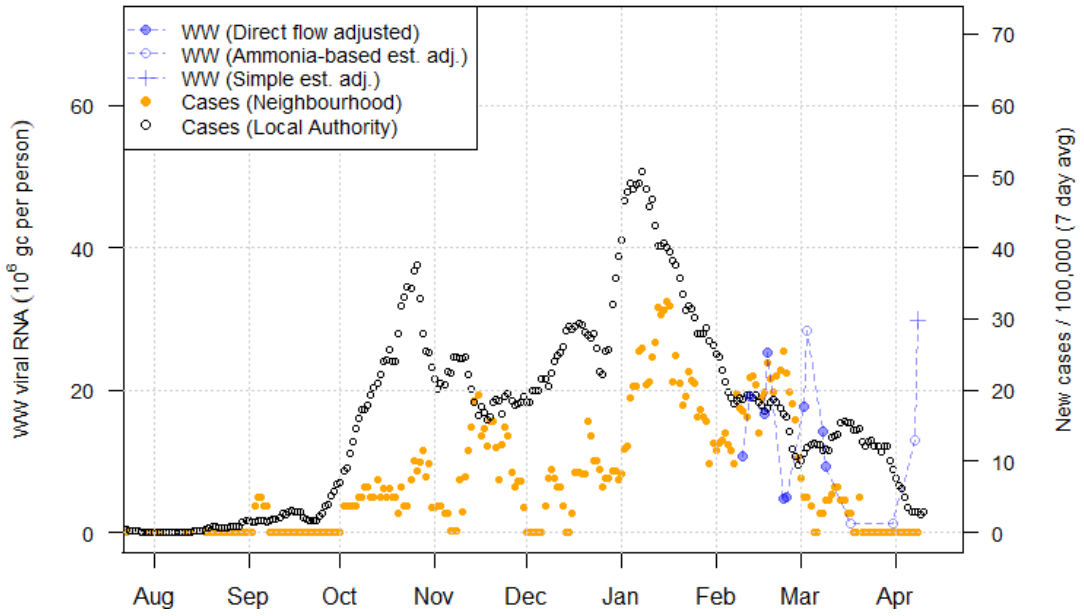
In contrast, NHS Borders (Figure 18) shows much lower wastewater Covid-19 and case rate levels than the Scottish average, declining quickly from its peak in early January to almost zero by the end of February. Note that wastewater catchment coverage for the Borders region is less complete (about 50%) due to its more rural nature (9 sites with mean population of 7k). However, the case rate and wastewater Covid-19 levels do match up quite well.

Figure 18. Wastewater Covid-19 and daily case rate (7 day moving average) in the Borders Health Board (pop: 116 k)



We are working to adapt our map representation to show the expanded set of sites. In the meantime, we note that for Largs in North Ayrshire (Figure 19), we have two consecutive readings showing increasing wastewater Covid-19 levels while case levels remain below censoring thresholds. This may show an undetected outbreak.

Figure 19. Wastewater Covid-19 and daily case rate (7 day moving average) for Largs in North Ayrshire (pop: 13k)



What next?

The Scottish Government continues to work with a number of academic modelling groups to develop other estimates of the epidemic in Scotland.

The modelled estimates of the numbers of new cases and infectious people will continue to be provided as measures of the epidemic as a whole, along with measures of the current point in the epidemic such as R_t and the growth rate. Further information can be found at https://www.gov.scot/coronavirus-covid-19.

Investigations are ongoing by NERVTAG, SPI-M, SAGE and Scottish Government regarding the impact of the new variant, SARS-CoV-2 VOC 202012/01, which will be reflected here as work is undertaken.

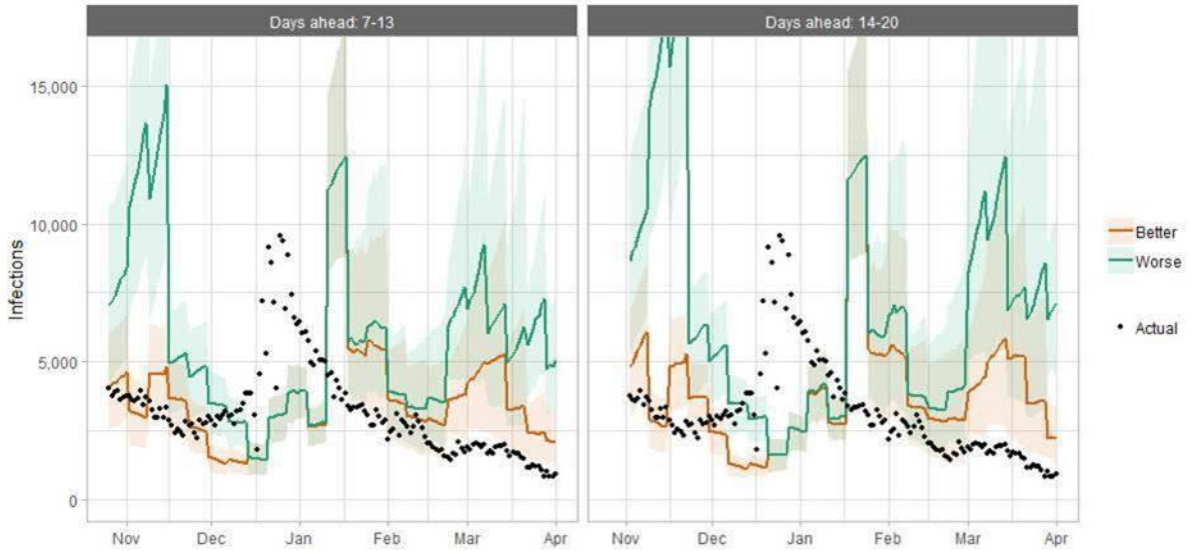
Analysis from the EAVE 2 group, which tells us about the pattern of demographics and clinical risk groups over time for those who are testing positive with Covid-19, will be provided in future issues.

Technical Annex

How the modelling compares to the real data as it emerges

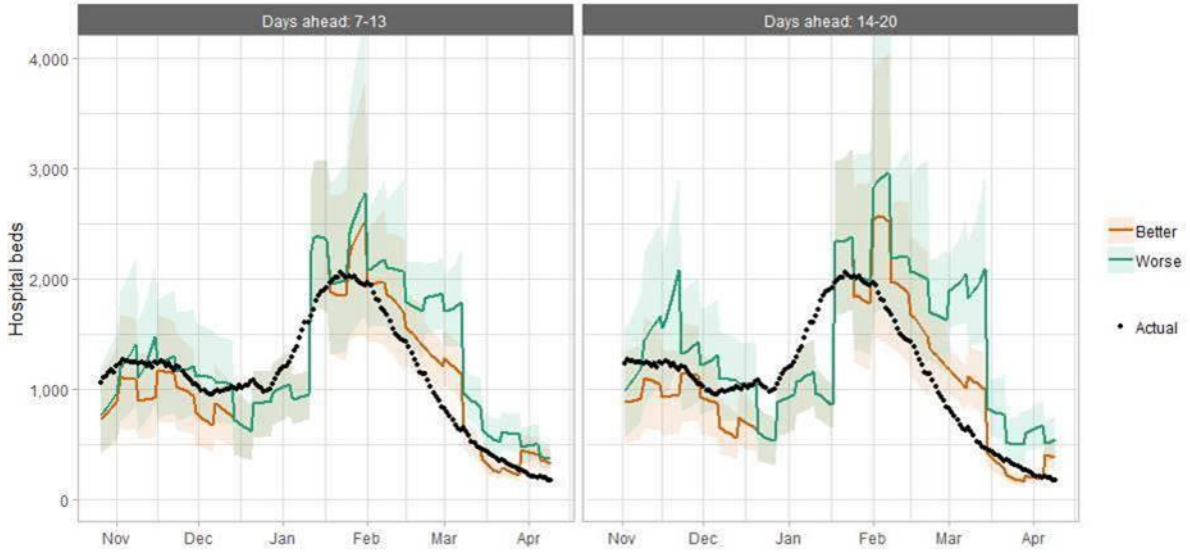
The following charts show the history of our modelling projections in comparison to estimates of the actual data. The infections projections were largely accurate during October to mid-December and from mid-January onward. During mid-December to mid-January, the projections underestimated the number of infections, due to the unforeseen effects of the new variant.

Figure 20. Infections projections versus actuals, for historical projections published between one and three weeks before the actual data came in.



Hospital bed projections have generally been more precise than infections estimates due to being partially based on already known information about numbers of current infections, and number of people already in hospital. The projections are for number of people in hospital due to Covid-19, which is slightly different to the actuals, which are number of people in hospital within 28 days of a positive Covid-19 test.

Figure 21. Hospital bed projections versus actuals, for historical projections published between one and three weeks before the actual data came in.



As with hospital beds, ICU bed projections have generally been more precise than infections. The projections are for number of people in ICU due to Covid-19. The actuals are number of people in ICU within 28 days of a positive Covid-19 test up to 20 January, after which they include people in ICU over the 28 day limit.

Figure 22. ICU bed projections versus actuals, for historical projections published between one and three weeks before the actual data came in.

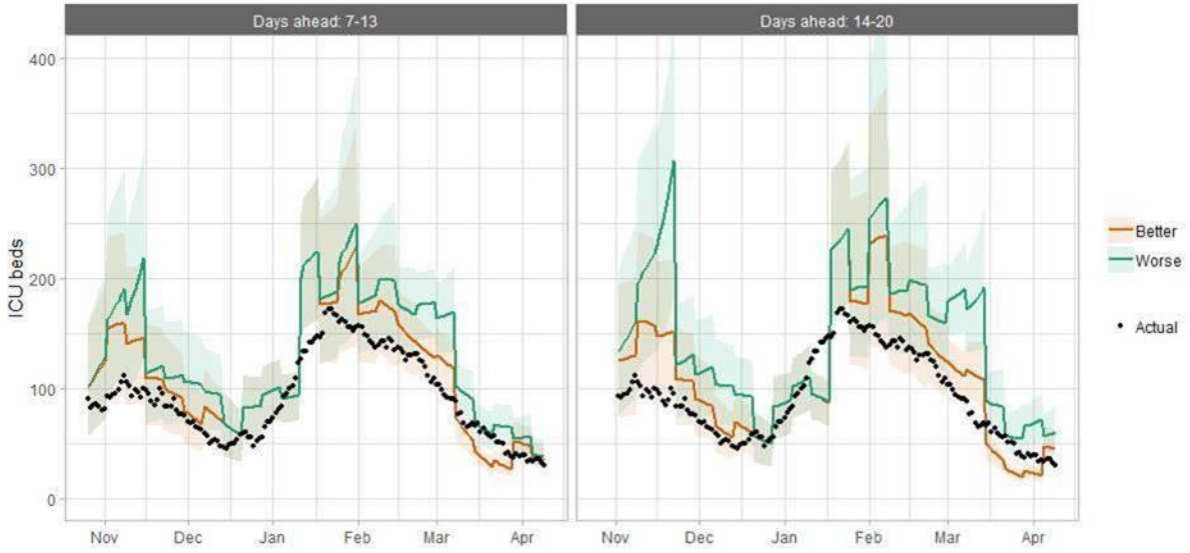


Table 1. Probability of local authority areas having more than 50, 100, 300 or 500 cases per 100K (25 April – 1 May 2021).
Data updated on 14 April.

LA	P (Cases > 500)	P (Cases > 300)	P (Cases > 100)	P (Cases > 50)
Aberdeen City	0-5%	0-5%	0-5%	5-15%
Aberdeenshire	0-5%	0-5%	0-5%	0-5%
Angus	0-5%	0-5%	0-5%	0-5%
Argyll and Bute	0-5%	0-5%	0-5%	0-5%
City of Edinburgh	0-5%	0-5%	0-5%	0-5%
Clackmannanshire	0-5%	5-15%	25-50%	25-50%
Dumfries & Galloway	0-5%	0-5%	0-5%	0-5%
Dundee City	0-5%	0-5%	0-5%	5-15%
East Ayrshire	0-5%	0-5%	0-5%	5-15%
East Dunbartonshire	0-5%	0-5%	0-5%	0-5%
East Lothian	0-5%	0-5%	0-5%	0-5%
East Renfrewshire	0-5%	0-5%	0-5%	5-15%
Falkirk	0-5%	0-5%	0-5%	5-15%
Fife	0-5%	0-5%	0-5%	15-25%
Glasgow City	0-5%	0-5%	0-5%	5-15%
Highland	0-5%	0-5%	0-5%	0-5%
Inverclyde	0-5%	0-5%	0-5%	5-15%
Midlothian	0-5%	0-5%	0-5%	0-5%
Moray	0-5%	0-5%	0-5%	15-25%
Na h-Eileanan Siar	0-5%	0-5%	0-5%	0-5%
North Ayrshire	0-5%	0-5%	0-5%	0-5%
North Lanarkshire	0-5%	0-5%	0-5%	5-15%
Orkney Islands	0-5%	0-5%	0-5%	0-5%
Perth and Kinross	0-5%	0-5%	0-5%	0-5%
Renfrewshire	0-5%	0-5%	0-5%	15-25%
Scottish Borders	0-5%	0-5%	0-5%	0-5%
Shetland Islands	0-5%	0-5%	5-15%	5-15%
South Ayrshire	0-5%	0-5%	0-5%	0-5%
South Lanarkshire	0-5%	0-5%	0-5%	0-5%
Stirling	0-5%	0-5%	0-5%	5-15%
West Dunbartonshire	0-5%	0-5%	0-5%	0-5%
West Lothian	0-5%	0-5%	0-5%	5-15%

The local estimates should be interpreted with caution as they are based on fewer models than previous reports.

Exceedance

Exceedance is defined by Health Protection Scotland as a greater than expected rate of infection compared with the usual background rate for the place and time where the incident has occurred[11]. We assume that the daily number of new positive cases should fall within a certain distribution of values, given the number of tests carried out each day, and the proportion of those we expect to be positive.

The probability of getting the observed value of positive tests or greater can then be calculated. If this probability is small, the daily number of positive cases is much larger than would be expected by chance. We can now provide this at Local Authority level in Scotland using a model developed and run by Warwick University using Scottish testing data.

We can aggregate positive test results across several days to identify periods when the proportion of confirmed infections is high. This “cumulative exceedance” measure is more robust as it smooths variability in the data caused by, for example, multiple cases within larger households. As this cumulative exceedance value falls back to background levels, we can be confident that any outbreaks have been dealt with.

Daily Exceedance

The daily exceedance is a measure of how far above the expected number of positive tests today's results are, based on the number of tests, the national tests and the particular attributes of each Local Authority.

The expected proportion of positive tests for a given Local Authority is based on the daily pattern of positive tests from elsewhere in the country (and hence naturally accounts for the impact of both a declining epidemic and the impact of weekend effects); this value is scaled by the mean proportion of positive tests in the Local Authority over the past six weeks. We assume that the daily number of new positive cases should be drawn from a binomial distribution for the given number of tests and the expected proportion positive. The probably of getting the observed value or above can then be calculated. When this is small, the daily number of positive cases is much larger than would be expected by chance. We define the exceedance as:

- log (probability of getting today's number of positive cases or higher by chance)

Large values correspond to highly unlikely large positive values.

Recent Cumulative Exceedance

We can apply this approach backwards in time, to assess whether a Local Authority has had consistently high values over a period of many days. Again assuming a binomial distribution, we calculate the probability of observing the given cumulative number of positive cases over a given period compared with the expected number.

[11] Healthcare infection incidents and outbreaks in Scotland

This publication will be available in accessible HTML on the gov.scot website

The views expressed in this report are those of the researcher and do not necessarily represent those of the Scottish Government or Scottish Ministers.

This document is also available from our website at www.gov.scot.
ISBN: 978-1-80004-938-3

The Scottish Government
St Andrew's House
Edinburgh
EH1 3DG

Produced for
the Scottish Government
by APS Group Scotland
PPDAS864606 (04/21)
Published by
the Scottish Government,
April 2021

ISBN 978-1-80004-938-3

Web Publication

PPDAS864606 (04/21)