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Identifying key weather factors influencing human salmonellosis: A conditional incidence analysis in England, Wales, and the Netherlands

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S U M M A R Y

Objectives: This study aimed to improve the understanding of seasonal incidence pattern observed in salmonellosis by identifying the most influential weather factors, characterising the nature of this association, and assessing whether it is geographically restricted or generalisable to other locations.
Methods: A novel statistical model was employed to estimate the incidence of salmonellosis conditional to various combinations of three simultaneous weather factors from 14 available. The analysis utilised daily salmonellosis cases reported from 2000 to 2016 along with detailed spatial and temporal weather data from England and Wales, and the Netherlands.
Results: The incidence simulated from weather data effectively reproduced empirical incidence patterns in both countries. Key weather factors associated with increased salmonellosis cases, regardless of geographical location, included air temperature (> 10 °C), relative humidity, reduced precipitation, dewpoint temperature (7–10 °C), and longer day lengths (12–15 h). Other weather factors, such as air pressure, wind speed, temperature amplitude, and sunshine duration, showed limited or no association with the empirical data. The model was suitable for the Netherlands, despite a difference in case ascertainment.
Conclusions: The conditional incidence is a simple and transparent method readily applicable to other countries and weather scenarios that provides a detailed description of salmonellosis cases conditional on local weather factors.
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Introduction

Salmonella is an important zoonotic causative agent of diarrhoeal disease worldwide, being the pathogen most frequently involved in food-borne outbreaks in Europe. In 2021, a total of 60,050 confirmed salmonellosis cases were reported across the European Union, with a notification rate varying from 15.7 to 19.7 cases per 100,000 population over the past 5 years.[1] Although symptoms are usually mild, salmonellosis can result in a febrile invasive disease with an overall pooled case-fatality ratio of 14.7% (95% CI 12.2–17.3).[2]

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There is increasing evidence that weather plays a crucial role in the transmission of salmonellosis.[3,4] Higher incidence rates are typically observed in late summer in temperate regions,[5] and temperature is often positively associated with the incidence of salmonellosis.[6–8] However, the relationship between salmonellosis occurrence and climatic factors is complex and multifaceted. For example, while the survival of *Salmonella* decreases at higher temperatures in animal effluents, soils, and surface waters, *Salmonella* detection in poultry increases at higher temperatures. Other factors, such as moisture levels, freeze-thaw events, wind patterns, and sensitivity of different *Salmonella* strains to temperature variations, further complicate the picture. These factors can potentially influence disease severity and transmission dynamics.[4] Understanding these complexities is crucial for effective management and prevention strategies, and to enhance our ability to forecast the risk of disease. This is especially the case in the light of climate change,[16] given recent research findings that a continuation of current climate trends could lead to increased patient morbidity and hospitalisation linked to food-borne bacterial pathogens.[13] Climate change has also been associated with more extreme weather events,[17] as well as a change in general climate trends. These extreme weather events can contribute to an increased incidence of diseases, including salmonellosis.[4,18]

A recent meta-analysis based on 23 *Salmonella* studies showed that the risk of non-typhoidal *Salmonella* rose by 5% (RR: 1.05, 95% CI: 1.04–1.06) for each 1 °C rise in temperature.[9] This is consistent with another meta-analysis, which found that a 1 °C increase in temperature raises the estimated risk of salmonellosis by between 3% and 13%, with an estimated pooled relative risk of 1.05 (95% CI 1.04 to 1.07)[8]. Similarly, precipitation has been a key focus of seasonality studies, which have found a varying effect on *Salmonella* depending on the region of the world studied.[10–12] A pooled incidence rate ratio of 1.09 (95% CI: 0.99, 1.19) was found for extreme precipitation events for *Salmonella* and *Campylobacter.*[13] Increasing temperatures, together with unexpected extreme rains, may increase the health burden and economic costs of salmonellosis in coming years.[7,14]

The association between disease and weather has been consolidated with the advances in weather forecast and the availability of high-resolution predictions, motivating the development of predictive models. Some of the common modelling approaches include regression, time series and Bayesian analysis.[15] While these techniques prove to be pragmatic for the purpose of forecasting, they rely on data fitting. This involves using statistical or machine learning approaches to estimate the parameters of a given model that best explain the data,. However, this can make it difficult to isolate the individual effect of each variable on the outcome and to understand how the model generates its predictions.

Finally, although the linkages between climate, *Salmonella* incidence, and disease are well-described, high-resolution spatial analysis of salmonellosis has seen only limited investigation. Studies have identified spatial and temporal patterns in Australia,[19] but only at the province level, and in New Zealand[20] but only at the city level, focusing only on temperature as risk factor. The question of whether it is possible to accurately predict the incidence of salmonellosis at more granular spatial resolutions, with a wider range on relevant weather determinants as proxy of risk factors, has not been addressed. The objectives of this study are to employ UK postcode level data of diagnostic laboratories to (1) identify *which* and *how* specific weather factors are associated with salmonellosis incidence, (2) test whether we can exploit weather information to predict the risk of salmonellosis, and (3) assess whether the weather-infection relationship is geographically dependent or potentially generalisable to other locations. To address these points, we conducted a comprehensive investigation of the effect of 14 weather factors on salmonellosis at high spatio-temporal resolution and exploring different factor combinations.

Data and methods

Data

Salmonellosis incidence, weather and population data were pooled over time on the day infections occurred. This probable day of infection was estimated from the date the specimen was collected from the patient, after correcting for an estimated incubation period per major serotype, and reporting delays (appendix p 4). Reporting patterns were assumed to be temporally and spatially invariable.

Daily national surveillance data of confirmed salmonellosis cases reported to the UK Health Security Agency (UKHSA) in England and Wales during 2000–2016, and daily cases reported to the National Institute for Public Health and the Environment in the Netherlands (RIVM) during 2015–2019 were used. All cases were culture-confirmed by a diagnostic laboratory. The reported cases were filtered by selecting *Salmonella* subspecies of foodborne interest (*i.e.*, *Salmonella enterica* subsp. *enterica*) and cases with confirmed travel history or unknown patient residence were excluded. Where a specific patient was re-assessed for an on-going salmonellosis diagnosis, only the first recorded isolate within a 3-month window was included in the analysis. Further information about the diagnostic methods, serotyping, and coverage has been published elsewhere.[21]

The choice of the study period ensured that no significant changes in the control strategies (*e.g.*, mandatory poultry vaccination in the UK in 1998) occurred during this period. Despite this, the incidence shows a smooth downward trend from the year 2000. Thus, the data were detrended to correct for potential reporting bias, human behaviour and other unknown factors influencing the number of reported cases (appendix p 2).[22] The detrended data, which resulted in a seasonal time-series of salmonellosis cases with an overall mean equal to one, were multiplied by the average number of cases reported in the last 5 years to give an updated dimension to the results (*i.e.*, 15.4 daily cases for the years 2011–2016 in England and Wales, and 2.04 cases in the Netherlands for the study period (years 2015 to 2019).

The 207 diagnostic laboratories in England and Wales were linked to the specific catchment areas they serve. The annual number of residents of each catchment area were estimated by UKHSA from the resident mid-year population estimates of the National Online Manpower Information System, from the Office for National Statistics UK (Nomis) available at Lower Supper Output Area (LSOA) resolution. Salmonellosis cases were linked to local weather conditions in the catchment areas rather than to personal address due to data limitations and patient data protection.[23]

Given the relevance of food as route of transmission of *Salmonella,*[24] weather factors that are likely to have an effect on food were included. Certain weather factors (*e.g.*, relative humidity, dewpoint temperature, air pressure) can facilitate the availability of water for bacteria to multiply, while temperature and radiation can directly affect the structure and stability of food products. Weather can have an indirect effect on consumer behaviour, such as eating outdoors or improperly storing prepared food on sunny days.[12]

Fourteen daily weather (or astronomical, in the case of day length) factors for England and Wales were extracted or calculated at the postcode of the diagnostic laboratories *via* the Medical and Environmental Data Mash-up Infrastructure (MEDMI) platform.[25] Namely, maximum and mean air temperature, temperature variation (the difference between maximum and minimum air temperature), dewpoint temperature, surface air pressure, relative humidity, mean precipitation, cumulative precipitation, sunshine duration, global radiation and day length. The effect of indoor temperature and humidity conditions in the incidence of salmonellosis, based on values of outdoor mean temperature and relative humidity and assuming a thermal comfort of 21 °C were also included.[26] Weather factors may have a continuous effect on the occurrence of an infection (*e.g.*, effect on the bacterial community and/or people behaviour). Therefore, a rolling mean of the weather conditions for the 7 days prior to the day of infection was used. The only exception was cumulative precipitation, for which the daily value of precipitation was summed over the chosen time-lag. Other time-lags (14, 30 and 60 days) were explored with limited changes in the model predictions (appendix p 3).

Statistical analysis

The approach, based on the methodology developed for campylobacteriosis,[23] consisted of two main steps: i) evaluation of the incidence of salmonellosis conditional to the weather factors, and ii) generation of the time-series of cases based on the local weather factors and number of residents.

Initially, a combination of three weather factors of interest (*e.g.*, maximum air temperature, precipitation and global radiation) was selected. Thereafter, all situations in the entire dataset that matched a chosen set of discrete weather factors values, regardless of location and day of the year, and averaged them over a certain number of past days were selected. For example, all instances where the average value of the maximum air temperature over the last 7 days was between 15 and 16 °C, the average precipitation was between 0 and 1 mm, and the average global radiation was between 1000 and 1500 Wm^{-2}. The conditional incidences were calculated as the total number of cases reported during each specific set of weather combinations, divided by the total number of residents exposed to the same weather conditions, P_{cond}. The ratio P_{cond} represents the daily incidence of detecting a case given the specific weather values (expressed here per million people).[23] The conditional incidence for the Netherlands was also estimated for comparison.

The conditional incidence estimated above was then used to simulate the time-series of expected number of cases, at a particular location given the weather factors. We assumed that infection cases were random occurrences, with negligible human-to-human transmission, governed by a Poisson process with a rate of infection equal to the expected daily number of salmonellosis cases in each catchment area. The rate was calculated by ascertaining the weather factors in a catchment area, estimating the corresponding conditional incidence, and multiplying it by the number of residents of the said area.

The performance of the model under different weather factor combinations was assessed by several methods. An overall goodness of fit was measured by R-squared and RMSE (appendix pp 4–7). The number of cases predicted for each catchment area and for each day was also compared with the observed number of cases in a scatter plot (appendix p 8). The points in the scatter plot were fitted using a generalised linear model with identity link function and the intercept and slope calculated. In an ideal scenario, the points on the plot would fall along a diagonal line with an intercept close to zero and a slope close to one.

The expected number of salmonellosis cases was estimated in each 5×5 km of a geographical grid covering the territory of the Netherlands, based on the local weather data number of residents, but using the weather-conditioned incidence, P_{cond}, estimated from the surveillance data from England and Wales, as well as from the Netherlands for comparison. Predictions of the model were compared with laboratory-confirmed cases reported to the RIVM for the years 2015 to 2019. The year 2020 was dismissed due to altered reporting patterns linked to the COVID-19 pandemic.[27] The weather data were obtained from the Netherlands Royal Meteorological Institute (www.knmi.nl/klimaat) and the residents' information from Statistics Netherlands (www.cbs.nl/en-gb) at full 6-digit postal code level. Weather, cases reported, and residents' data were harmonised spatially at a 5 km grid resolution using QGIS Desktop version 3.16 "Hannover". Weather factor combinations for the Netherlands that did not have corresponding values in The England and Wales dataset were excluded from the analysis. This resulted in 2.5% of Dutch weather data not being accounted for by the conditional incidence determined from England and Wales. To address differences between countries that would affect the conditional incidence, such as lower reporting rates, salmonellosis cases were rescaled. This was done by using a constant coefficient calculated by multiplying the average number of cases reported in the Netherlands by the ratio of the average number of residents in the Netherlands divided by the mean number of residents in England and Wales during the same study period.

Results

Epidemiology

The salmonellosis cases included in the analysis were 144,703 reported in England and Wales (average annual incidence rate 14.92 ± 5.13 per 100,000 from 2000 to 2016) and 3231 (4.60 ± 0.51 per 100,000) in the Netherlands between 2015 and 2019. An exploratory analysis of the data for the years studied identified a notably higher incidence of salmonellosis in the younger age groups (*i.e.*, 0–4 years old), followed by > 90 years in England and Wales, while for the Netherlands, the highest incidence was found in young patients between 5–29 years. The distribution of cases by sex was comparable in both countries.

In terms of the prevalence of the different *Salmonella* serotypes, *S.* Enteritidis was the predominant serotype for both countries. In England and Wales, the top three most common serovars were: *S.* Enteritidis (58.2%) > *S.* Typhimurium (including monophasic variant) (19.15%) > *S.* Virchow (3.3%), with a small proportion of unknown serotypes (2.9%). In the Netherlands, the two most common serotypes coincided with England and Wales, although in different proportion (*S.* Enteritidis (28.63%) > *S.* Typhimurium (27.37%) > *S.* monophasic Typhimurium (13.61%)). In case of considering together the monophasic variant of Typhimurium within the Typhimurium serotype (as it was considered in England and Wales), then the proportion changed (*S.* Typhimurium = 40.98%), being greater than that of *S.* Enteritidis.

Evaluation of the incidence of salmonellosis conditional to the weather factors in England and Wales

The impact of each weather factor on the risk of salmonellosis was not linear and depended on the interactions between them (Fig. 1 and appendix pp 14–25). Overall, an increased risk was found for mean temperatures ≳ 5 ºC (Fig. 1A), but ≳ 10 ºC for day length between 12 and 15 h (Fig. 1C), maximum temperatures ≳10 ºC, with notably higher risk for temperatures > 15 ºC during day of 12 to 15 h length, and dewpoint temperature > 5 ºC for the dame day duration (appendix pp 18–24). Global radiation displayed higher uncertainty, as observed in the width of the ribbons (appendix p 25), due to the variability of its values, with a higher risk observed for radiation values between 3696–15,294 kJ/m^2. Relative humidity had a variable influence, with lower risk for drier conditions at higher temperatures when days were longer (greater than 15 h-long, corresponding to the months of June and July), and higher risk for the same weather conditions for 9 to 15 h of day duration (typically March to May and mid-August to October) (appendix pp 21 and 20). The variable risk associated with different day lengths went unnoticed when only considering the isolated influence of day length for longer days, which flattens from 12 h onwards (Fig. 1B). Relative humidity, precipitation, wind speed, and air pressure had a less pronounced impact on salmonellosis cases compared to temperature and day length

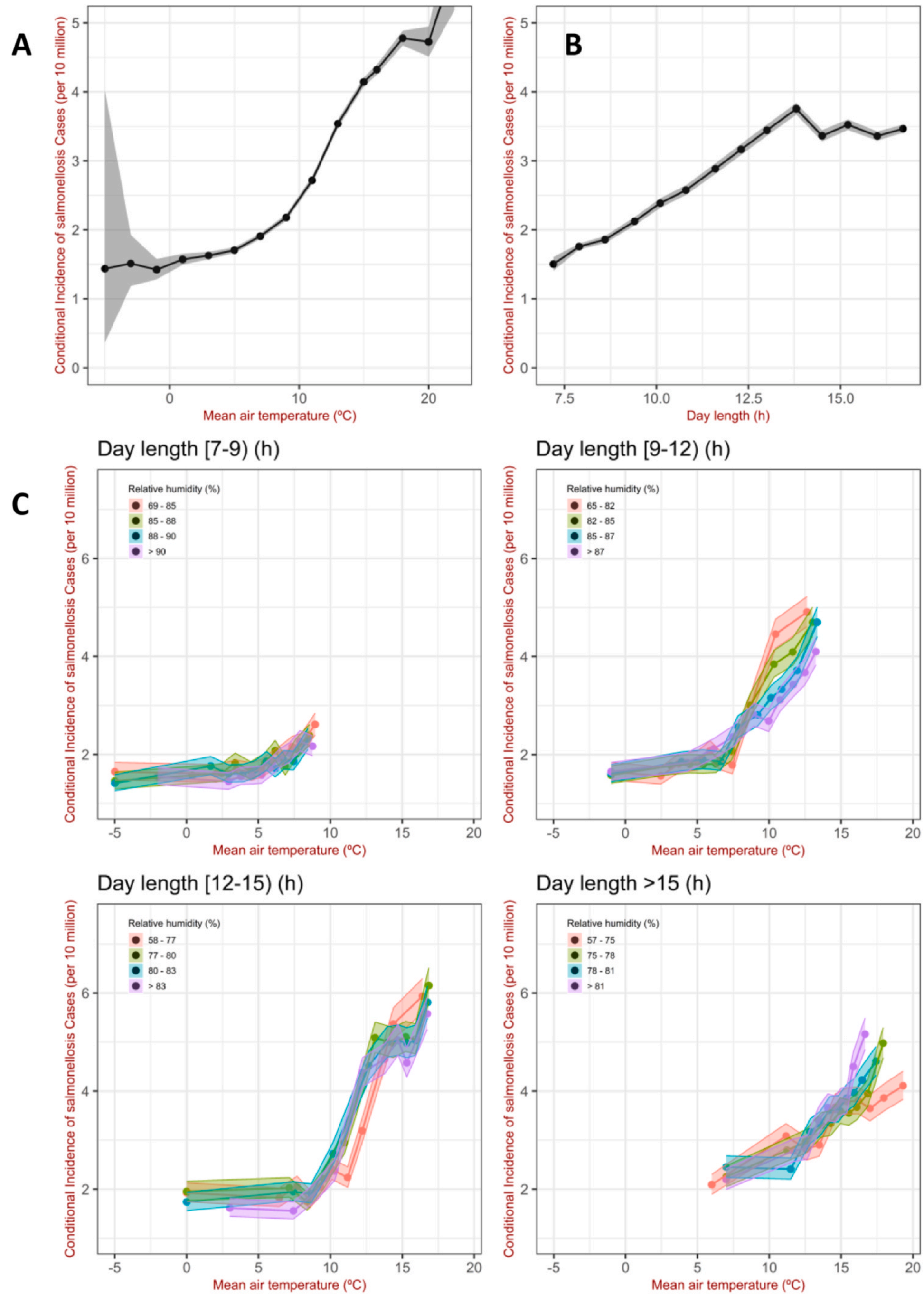

Fig. 1. Number of salmonellosis cases per 10 million habitants per day based on the isolated effect of mean air temperature (A), day length (B), and the combined effect of mean air temperature, relative humidity, and day length (C) as an example of complex weather interactions. The effect of mean air temperature for a subset of relative humidity values is captured for a day length interval in each quadrant. See appendix pp 14–17 for the isolated effect of the other weather factors.

(or global radiation). This is evidenced by the overlapping profiles of conditional incidence (Fig. 1C and appendix pp 18–24).

Generation of the time-series of cases based on the local weather factors and number of residents

The model successfully replicated reporting patterns, capturing the main seasonal peak of salmonellosis incidence between August and September when relevant weather factors combinations were incorporated (Fig. 2). Spatial variability was also well captured (see, for example, appendix p 8). Specifically, combinations involving day length, temperature (maximum, mean air temperature, and dewpoint temperature), relative humidity, and precipitation (mean and cumulative) led to better predictions compared to the observations (table S1). This suggested that these were key explanatory factors influencing the incidence of salmonellosis in England and Wales. The complete weather factor combinations assessed are displayed in the supplementary material (appendix pp 9–13).

The R-squared values of the different weather factor combinations illustrated a marked schism at the value 0.45, in what could be considered the delimitation between best and worst performing combinations (Fig. 3). This exercise gives important indications of the combinations of weather factors that can be ruled out, *e.g.*, those involving temperature amplitude and sunshine duration. We

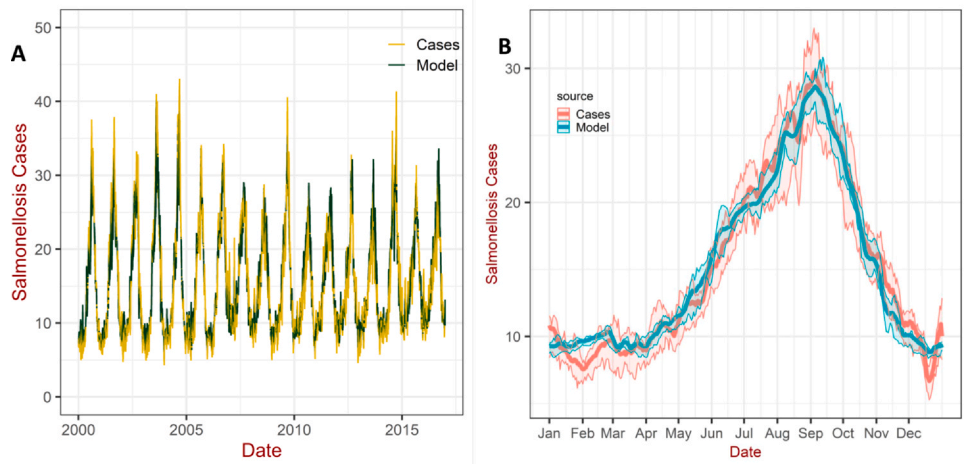

Fig. 2. A. Time-series of modelled and laboratory-confirmed reported cases of salmonellosis across England and Wales at daily resolution. B. Seasonal patterns for daily salmonellosis cases averaged over the entire study period. The shaded area represents the 25% and 75% quantiles. Weather factors analysed: mean air temperature, relative humidity, and day length.

discourage, however, establishing a fixed ranking of the performance of combinations, mainly because the different uncertainties in the measured weather factors arising, for instance, from the instrumental errors. It is worth noticing that outdoor weather conditions exhibited a better agreement than the estimated indoor values (appendix p 13). Furthermore, by visual inspection, the effect of day length and temperature, relative humidity, and precipitation had a notably greater predictive role for the peak of salmonellosis notifications (appendix pp 9–11).

Application of the conditional incidence model in the Netherlands

Fig. 4 shows the conditional incidence based on surveillance and weather data from the Netherlands. The conditional incidence was affected by large uncertainty due to the lower amount of data. The trend in the profiles to a certain degree was qualitatively similar to the profiles of the conditional incidence for England and Wales, (*e.g.*, flat profile for shorter day length, followed by an increase for a day length between 9–15 h). However, the magnitude of the conditional incidence was consistently lower. This was to be expected considering that non-typhoid salmonellosis is notifiable in England and Wales,[28] while sporadic cases are reported in a voluntary basis in the Netherlands.[21]

A favourable agreement between modelled and historical cases for the Netherlands was observed (Fig. 5 A-B), even if based on patterns of conditional incidence from England and Wales. The cases predicted by the model broadly captured the reporting patterns, including the summer peak. The greater variability in the predictions (*e.g.*, more frequent spikes) was expected due to the lower number of simulations. The predictions based on the conditional incidence calculated in the Netherlands resulted in a satisfactory expected match with the actual reported data, as it did in England and Wales (Fig. 5 C-D).

Discussion

Advancement in relation to commonly used methods

Regression models can provide useful insights into the underlying relationships between various variables and can help to identify important factors that influence disease forecasting. For example, looking at the association between disease and weather conditions using a general linear or general additive model. Time series models, such as ARIMA (Autoregressive Integrated Moving Average) and its variations (SARIMA, ARMA, ARIMAX, *etc.*), are routinely used in public health institutions to analyse and predict future disease events based on patterns of previous health data.[29–31] These models assume an accumulative effect in the transmission of a diseases in a population from one day to another, allowing them to make effective and short-term incidence predictions. However, some of the limitations of most regression and time series models are their limited ability in capturing non-linear and/or non-additive relationships between variables, and reduced capacity to capture the effects of external factors or interaction between variables.

The conditional incidence is an important source of information that allows to disentangle the associations of individual weather factors given certain levels of the other two weather factors. This study investigated the association between relevant weather factors and the incidence of human salmonellosis. There is a large literature analysing the effect of a limited number of isolated predictors, mainly temperature and precipitation, usually at a low spatial resolution and by means of regression models. Here, however, 14 meteorological factors and their three-way interplay were explored at a high spatial and temporal resolution, highlighting the effect of weather as a result of complex interactions of its components. This approach leveraged the linkage of 144,703 salmonellosis cases over 17 years in England and Wales with meteorological datasets, without relying on assumptions or regression models. The number of actual salmonellosis cases is known to be under-reported, with community cases estimated to be 40 times more than what is reported to national authorities in UK, and 20 in the Netherlands.[32] Thus, the conditional incidence and the predictions do not reproduce the true burden of diseases, but the detected cases. However, the temporal bias in case reporting is expected to be corrected, since the data have been detrended.

The conditional incidence, when multiplied by the number of residents in a catchment area, corresponds to the rate of infection in the underlying Poisson process.[23] The distributions of the rate of infection in 207 catchment areas across England and Wales were explored. A subset of these rates, which are stochastic due to randomness in the weather factors, was tested and found to be well approximated by gamma distributions. Therefore, we can infer that the Poisson distribution can be described by a negative binomial distribution correctly reproducing overdispersion in the data. Furthermore, the estimated number of cases were significantly lower in comparison to the overall population in each catchment area, naturally leading to a zero-inflated distribution of the modelled data.

To assess the performance of the model for different combinations of weather factors, two quantitative methods were used (R-

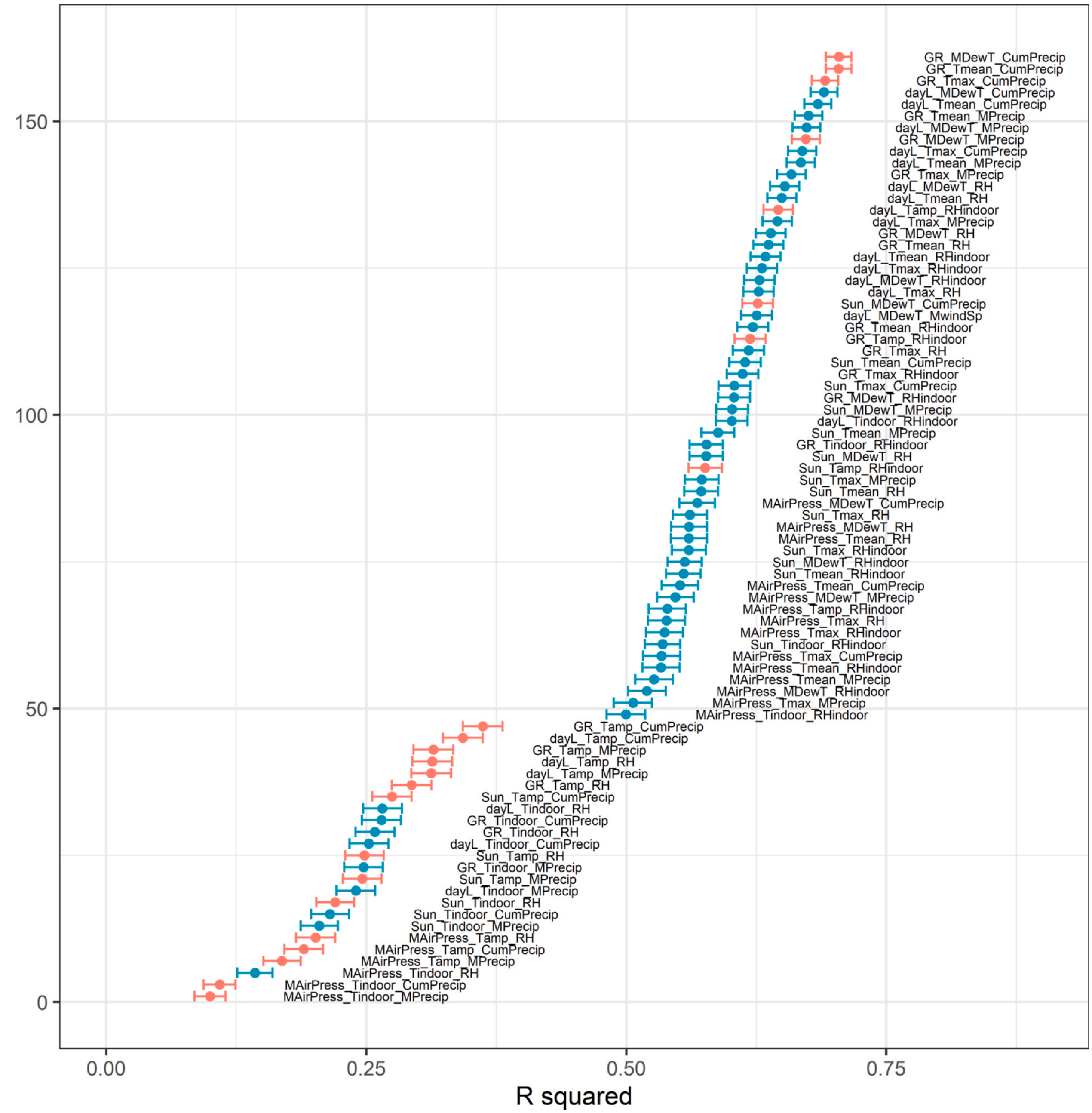

Fig. 3. R-squared values for all the different weather factor combinations with its corresponding error bar. In blue, situations where the coefficient's criteria are met (*i.e.*, the confidence interval for the intercept contains 0 and 1 for the slope). In red where the criteria are not met.

squared and RMSE). Accurate quantitative evaluation would require accounting for errors associated with the measurements/estimation of each weather factor, as well as uncertainties in the numerical scheme (*e.g.*, the bin size used in the computations), and the choice of the time-lag (which in principle could be different for different weather factors). A comprehensive error propagation analysis and sensitivity analysis was beyond the scope of this study.

Main weather factors combinations identified and irrelevant ruled out

The performance of the model in reproducing empirical cases of salmonellosis allows the identification of the most and least relevant weather factor combinations associated with salmonellosis. As observed in the case of campylobacteriosis,[23,33] the influence of the different weather factors is more complex than the result of their additive combination. Several combinations were considered satisfactory. The simultaneous effect of mean air temperature, relative humidity and day length stood out as a combination of common weather factors highly associated with human salmonellosis cases that could be used to estimate the cases reported for a specific area. Other suitable combinations included day length, precipitation and dewpoint temperature; and global radiation, mean temperature and precipitation. These findings are in line with previous studies that pointed at the isolated effect of temperature,[34–36] humidity[37] or rainfall[38] as important determinants of salmonellosis. Amongst the factor combinations of lesser or no relevance were the factors of snowfall, wind speed, sunshine duration, cloud cover, and vapour pressure, for which there are fewer studies.[31,34] All these studies identify a clear positive association between salmonellosis and temperature, although the influence of the other weather variables as well as their combined effect was less clear.[4]

Although food consumption tends to take place indoors, the statistical model used in this study reveals that outdoor weather

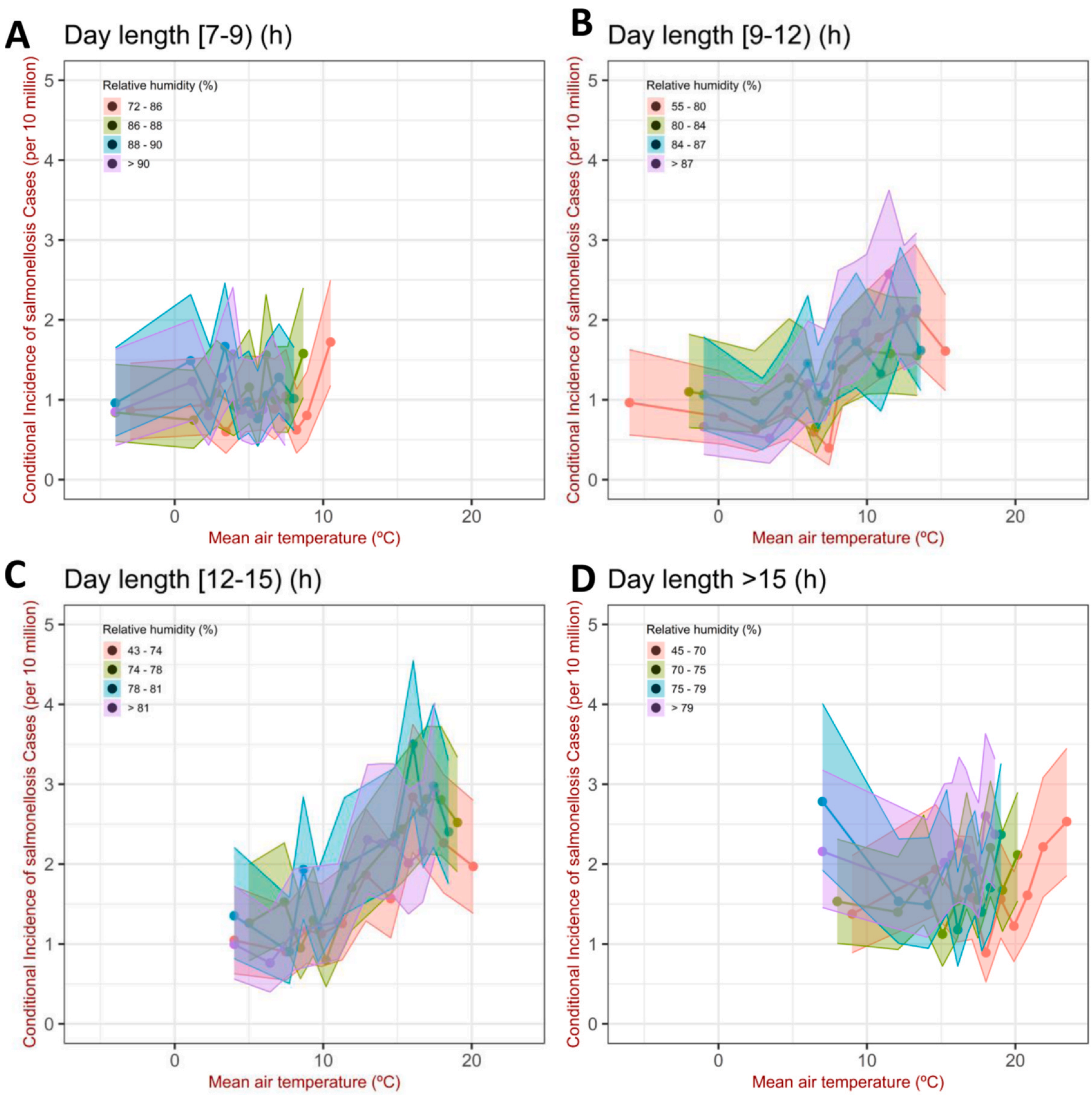

Fig. 4. As in Fig. 1, but based on salmonellosis and weather data from the Netherlands.

conditions performed better than indoor ones. It is to be expected that indoors settings are subject to greater environmental control, leading to more stable conditions compared to the outdoors. Therefore, seasonal incidence patterns are more likely to be related to outdoor events and the potential effect that weather has on them. For example, the spreading of infectious slurry, grazing practices and barbecue celebrations.

The conditional incidence can be generalisable to other countries and climate scenarios

When applying the conditional incidence calculated from incidence data from England and Wales to the Netherlands, the model broadly reproduced the patterns of salmonellosis incidence, provided that the predications are rescaled by a constant coefficient. This coefficient incorporates the country-specific features of the connection between surveillance data and human behaviour (*e.g.*, reporting patterns and health care-seeking behaviour of the patients), and location-specific particularities of *Salmonella* infections (*e.g.*, different serotype predominance, which may have a different response to weather, distribution of susceptible population, *etc.*).

Interestingly, the conditional incidence calculated from data from the Netherlands resembles the conditional incidence for England and Wales when rescaled by the same coefficient. The difference in reporting strategies in the two countries may play a role in the applicability of the model, as sporadic cases have epidemiologically different behaviour than outbreak-associated cases. The primary summer peak of incidence was identified by the model in the Netherlands, with minor discrepancies observed in June, July and October. Taken together, this indicates that the relationship between weather factors and salmonellosis, captured by the conditional incidence, is also applicable to the Netherlands, apart from a country-specific magnitude. To strengthen this conclusion, the model ought to be tested in countries with social and climatic conditions largely different from the UK, such as a low-income country and a country from a different hemisphere.

The conditional incidence opens the door to future research on mechanism of pathogenicity

In addition to weather, other relevant factors could also influence disease incidence, such as proximity to livestock farms,[5,39] human

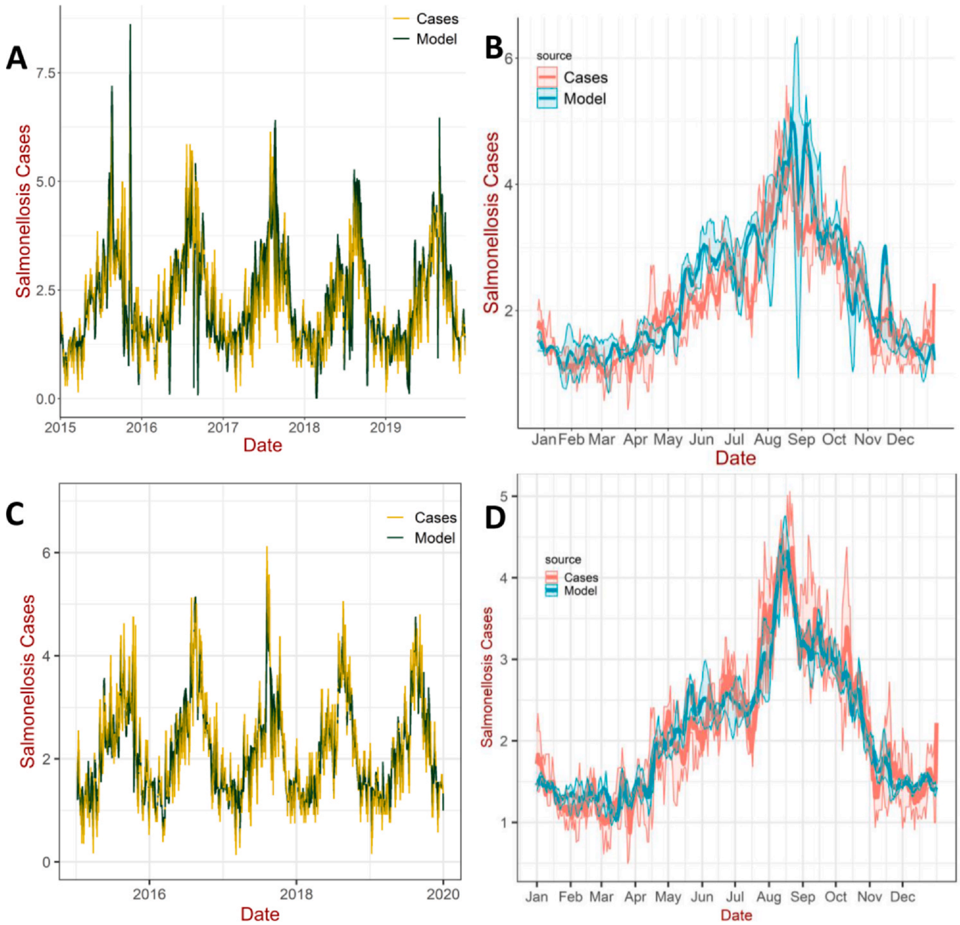

Fig. 5. As in Fig. 2, but for salmonellosis cases in the Netherlands. A and B using the Conditional Incidence estimated for England and Wales. C and D using the Conditional Incidence estimated for the Netherlands. Weather factors are mean air temperature, relative humidity, and day length.

behaviour and other environmental variables. The methodology can be applied to estimate the incidence of salmonellosis conditional to the average number of livestock present in a catchment area in a way to evaluate land use as a driving factor.

It is important to note that the associations between incidence and weather identified in the study do not delve into the mechanisms underlying seasonality. However, the methodology indirectly includes all potential and unknown mechanisms involved in the occurrence of human salmonellosis, such as higher bacteria growth rates in warmer temperatures, increased risky human activities such as summer outdoor picnics, or increased shedding of bacteria by stressed animal reservoirs on hot days. While the methodology does not identify the causal pathway of salmonellosis, the association with the relevant weather factors identified allow a benchmark to contrast potential mechanistic hypotheses. For example, to test the hypothesis of salmonellosis infection driven by outdoor barbecues on a warm day, chicken sales data could be added to the model as a variable. The results could be then used to feed a theoretical agent-based model that would mimic the mechanism of interest to be tested, and compared with the conditional incidence for acceptance or rejection of the hypothesis. A better understanding of disease behaviour is essential for disease preparedness and prevention, especially in relation to the increasing anthropogenic impact on the environment and climate change.

Data availability

Data used for the analysis for England and Wales are available upon request to the Environmental public health surveillance system. Queries should be sent to the EPHSS email address: ephss@ukhsa.gov.uk. Data for the Netherlands are provided as supplementary material. The R scripts with the methodology are available on the GitHub platform: https://github.com/lauracris-7/Salmonella_CI_UK_NL.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jinf.2025.106410.

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