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Ambient temperature and stillbirth risks in northern Sweden, 1880–1950

Lena Karlsson[a,b], Johan Junkka[a], Erling Häggström Lundevaller[a], Barbara Schumann[a,c]

Abstract

Background: Climate vulnerability of the unborn can contribute to adverse birth outcomes, in particular, but it is still not well understood. We investigated the association between ambient temperature and stillbirth risk among a historical population in northern Sweden (1880–1950).

Methods: We used digitized parish records and daily temperature data from the study region covering coastal and inland communities some 600 km north of Stockholm, Sweden. The data included 141,880 births, and 3,217 stillbirths, corresponding to a stillbirth rate of 22.7 (1880–1950). The association between lagged temperature (0–7 days before birth) and stillbirths was estimated using a time-stratified case-crossover design. Incidence risk ratios (IRR) with 95% confidence intervals were computed, and stratified by season and sex.

Results: We observed that the stillbirth risk increased both at low and high temperatures during the extended summer season (April to September), at −10°C, and the IRR was 2.3 (CI 1.28, 4.00) compared to the minimum mortality temperature of +15°C. No clear effect of temperature during the extended winter season (October to March) was found. Climate vulnerability was greater among the male fetus compared to the female counterparts.

Conclusion: In this subarctic setting before and during industrialization, both heat and cold during the warmer season increased the stillbirth risk. Urbanization and socio-economic development might have contributed to an uneven decline in climate vulnerability of the unborn.

Keywords: Stillbirth; Ambient temperature; Seasonality; Environment; Climate vulnerability; Sweden

Introduction

Stillbirth is defined by the WHO as the birth of a fetus that shows no signs of life after the 28th gestational week[1]; it is counted per 1,000 births, including live and stillbirths, and can vary considerably between populations. Globally, stillbirths are still a major public health problem, with the risk up to ten times higher in low-income countries when compared with high-income countries.[2] In the beginning of the 20th century, there were large geographical differences in stillbirth rates across Europe, ranging from below 20 to 167 stillbirths/1,000 births, related to differences in living conditions, but also owing to differences in registration and misclassification of stillbirths.[3]

In accordance with an increased interest in the association between environmental exposures and adverse birth outcomes, a number of recent studies have explored the effect of extreme temperatures on stillbirths, mostly regarding heat stress in tropical or temperate climates.[4–7] However, the role of heat and cold for stillbirths in subarctic climates has received less attention.[8]

In this study, we examined the association between ambient temperature and stillbirth risk in northern Sweden between 1880 and 1950, representing a time when this region underwent the transition from a predominantly agricultural society to an industrial one, with increased living standards and decreasing mortality rates.[9] The time period between the late 19th and the mid-20th century also corresponds to a change from mostly home-assisted births to a standard of giving birth in hospitals, and the expansion of maternal and obstetric health care in Sweden from 1930 onwards.[9,10] We hypothesized that the effect of ambient temperature on stillbirths changed in accordance with these societal improvements, as they were likely to cause a decline in the climate vulnerability of pregnant women and their fetus. Our objective was to assess the association between ambient temperature and the risk of stillbirth in northern Sweden in

What this study adds:

The association between ambient temperature and fetal health has been observed among contemporary populations. Few studies have explored the effect of temperature on stillbirth risk among historical populations over an extended period of time. We found an increased stillbirth risk during the summer season, especially among male fetuses. Our study adds knowledge of climate vulnerability in a subarctic setting and highlights the male disadvantage in terms of that climate vulnerability.

[a]Centre for Demographic and Ageing Research (CEDAR), Umeå University, Umeå, Sweden; [b]Department of Sociology, Umeå University, Umeå, Sweden; and [c]Department of Epidemiology and Global Health, Umeå University, Umeå, Sweden

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Results and data statement: The paper and the data have not previously been published, either in whole or in part, and that no similar paper is in press or under review elsewhere.

Corresponding Author. Address: Umea Universitet Samhallsvetenskapliga Fakulteten Umeå, Umeå, Sweden. E-mail: lena.karlsson@umu.se (L. Karlsson).

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1880–1950 and to investigate possible sex differences in climate vulnerability.

Temperature, seasonality, and stillbirth

The association between ambient temperature and stillbirth risk has been revealed in both pre-industrial and contemporary societies, as well as in different climates. A number of studies among contemporary populations in Canada and the USA showed an effect of heat on stillbirths,[4–6,11,12] whereas a few also found an effect of low temperatures.[12–14] Both long-term and acute extreme temperature were associated with a higher stillbirth risk compared with moderate temperatures.[12] Among studies conducted in Europe, Bruckner et al[8] showed that the stillbirth rate in Uppsala, Sweden, 1915–1929, increased with low weekly mean temperature during pregnancy. To our knowledge, no previous studies have investigated the association between ambient temperatures and stillbirth in a subarctic climate covering a longer time span during social and demographic transformations.

Studies in temperate climates show an increased stillbirth risk during winter and/or summer.[15,16] In colder climates (e.g. the US and Switzerland), the stillbirth risk generally increased during the winter, while for warmer climates (e.g. Australia) the risk increased in the summer.[17] Another study of stillbirths in Switzerland revealed an increased risk during spring (March to May) and during late autumn (October to December).[18] These differences in seasonal mortality risk between colder and warmer climates have also been shown for infants, children, and adults.[19]

In our previous research on seasonality and heat and cold effects on stillbirths and perinatal mortality in northern Sweden during the 19th century, we found that winter was a high-risk season and that there was an increased mortality risk during extreme winter cold.[20,21] Furthermore, there were large differences in climate vulnerability between indigenous and nonindigenous populations living in the same area, and between boys and girls.

Stillbirths in pre-industrial and industrializing Sweden

In Sweden, there was a sharp decline in stillbirth rates at the end of the 19th century, from 32.7/1,000 births in the 1860s to 24.8/1,000 at the beginning of the 1900s.[22] The tipping-point of stillbirth risk in Sweden around 1940 corresponded to the introduction of the large-scale institutionalization of maternal and child health care.[9] For the entire period of 1880–1950, boys had higher stillbirth rates when compared with girls, and this was especially notable in this northern part of Sweden.[22,23]

During the first two decades of the 20th century, the stillbirth rate in the northern area was generally lower compared with Sweden as a whole, followed by a somewhat higher stillbirth rate during the 1930s.[23]

Materials and methods

This study used a retrospective and long-term perspective of stillbirths by combining historical population records and temperature data from northern Sweden during 1880–1950.

Population data

The population data constituted of digitized parish records obtained by the Demographic Data Base, Umeå University.[24] The dataset used in this study includes the dates of birth and death, the gender, and the place of birth and death of every individual born or who moved into the study area from 1880 to 1950. The sample included 141,880 births, of which 3,217 were registered as stillbirths (Table 1). About 3% of the registered births have incomplete information about the cause of exiting the register (death, migration, etc.); however, our validation tests showed no seasonal differences in missing information. The study area covers three regions in Västerbotten County with available vital data during 1880–1950: Umeå and Skellefteå at the coast, and the "Inland region" northwest of the Skellefteå region. For these locations, also daily temperature data from nearby weather stations were available (Figure 1). Stillbirth rate was defined as the number of stillbirths/1,000 live births and stillbirths.

Temperature exposure

Stillbirth death has been shown to have a lagged response to ambient temperature up to a week after exposure.[4] We estimated temperature exposure as the average temperature over the past 7 days before birth or stillbirth.

Temperature data were obtained from the Swedish Meteorological and Hydrological Institute (SMHI),[25] which gives access to controlled data on an open data website (https://www.smhi.se/en/services/open–data/search-smhi-s-open-data-1.81004). Our temperature data included three daily measurements (morning, noon, and evening) from the weather station closest to the study area (Umeå, Bjuröklubb, and Stensele, respectively). The temperature data were controlled and validated by the SMHI, except for the following years: Umeå in 1940–1944 and 1946–1950 and Bjuröklubb in 1919–1948. For those years, we used noncontrolled data from SMHI.

Umeå weather data were used for stillbirths in Umeå's rural and urban parishes, Bjuröklubb weather data for Skellefteå (Sankt Olof, Bureå, Byske, and Lövånger), and Stensele weather data for Norsjö, Jörn, and Malå (inland region). The mean daily temperature was computed based on the three daily values (morning, noon, and evening). If some values were missing, the daily mean was calculated based on available measures from the current day, the day before, and the day after.

Statistical analyses

We used a time-stratified case-crossover design to analyze the data. The method is widely used to analyze associations between short-term exposures and health outcomes, such as mortality on a daily basis.[26–31] A case is a day with a stillbirth death, and all other days within the same month and the same year are control days. Hence, a case day has between 27 and 30 control days. This time period is considered a stratum and enables the estimation of acute temperature exposure effects in comparison to a reference temperature within the same stratum. The method allows for the estimation of effects that are unbiased from monthly and yearly variations. The effect of temperature exposure on stillbirth counts was estimated using a conditional Poisson model of the following form, as suggested by Armstrong et al.[30]

$$E\left(Y_{i,s} \mid \sum_i Y_{i,s} = \exp(\beta X_i)\right),\ Y_{i,s} \sim Poisson\left(\mu_{i,s}\right).$$

The expected count of death $Y_{i,s}$ in stratum s on day i is conditioned on the sum of events in each stratum, $\sum_i Y_{i,s}$, β is a vector of coefficients, and X is a model matrix of temperature exposures on day i. By conditioning on the stratum, the monthly and yearly effect, represented by the stratum, is in essence conditioned out.

The nonlinear relation between stillbirth and temperature was modeled as a cubic spline with three degrees of freedom (models M1, M5, and M7). In analyses on variations by extended season (M2 and M6), sex (M3), and time-period (M4), the temperature exposure effect was simplified, using a linear threshold function. The cut-off point of the function was set at the approximate breaking point between the minimum mortality temperature

Table 1.

Births, deaths, and stillbirth rates (per 1,000) in the study region, 1880–1950.

	Births	Stillbirths	Stillbirth rate
Extended season			
Ext. summer	71,848	1,597	23.1
Ext. winter	70,032	1,620	22.2
Season			
Summer	35,203	811	23.0
Autumn	34,612	763	22.0
Winter	35,285	768	21.8
Spring	36,780	875	23.8
Time-period			
1880–1899	32,554	669	20.6
1900–1929	67,171	1,417	21.1
1930–1950	42,155	1,131	26.8
Sex			
Girls	69,259	1,396	20.2
Boys	72,606	1,811	24.9
Unknown sex	15	10	666.7
Total	141,880	3,217	22.7

range and increasing mortality, at +15°C (90th percentile), over the whole year, −8°C (25th percentile) in the cold period of the year (October to March), and at +14°C (75th percentile) in the warm period (April to September) (Figures A3 and A9, Appendix; http://links.lww.com/EE/A164). The relative change in the effect was calculated as incidence risk ratios (IRR) with 95% confidence intervals (CI) over the temperature range where stillbirths were observed in comparison to the minimum mortality temperature.

The models were implemented in the statistical program environment R using the gnm function and the dlnm package.[32–34]

Additional analyses split the population by sex, by season (extended winter–October to March–and extended summer, April to September), and by period (1880–1899, 1900–1929, and 1930–1950). Sensitivity analyses were performed using splines for the extended season and restricting the strata to the same day of the week, month, and year. Analysis showed results similar to the main analysis (M5 in Figure A4 and M6 in A5 in Appendix; http://links.lww.com/EE/A164). Finally, additional analyses were performed exploring subweekly variations in vulnerability by estimating temperature exposures on a daily basis over the past 14 days (M7, Figure A6 in Appendix; http://links.lww.com/EE/A164).

Results

The stillbirth rate was highest in the Skellefteå region (23.6/1,000) and lowest in the inland (20.9/1,000) (Table 1). Boys had a substantially higher stillbirth rate compared to girls, 24.9/1,000 and 20.2/1,000, respectively. There were small seasonal differences, with the highest rate during spring (23.8/1,000) and the lowest rate during winter (21.8/1,000). Stillbirth rates were substantially higher among boys than girls, and there were variations across the study period (Figure A1, A7, and A8 in Appendix; http://links.lww.com/EE/A164).

The conditional Poisson model (M1), adjusted for seasonal and monthly variations, showed a nonlinear relation between temperature and stillbirths (Figure 2). The temperature with the lowest mortality was +15°C, and the IRR markedly increased as the temperatures approached 0°C. No further increase in risk was observed at temperatures below that point. Above the

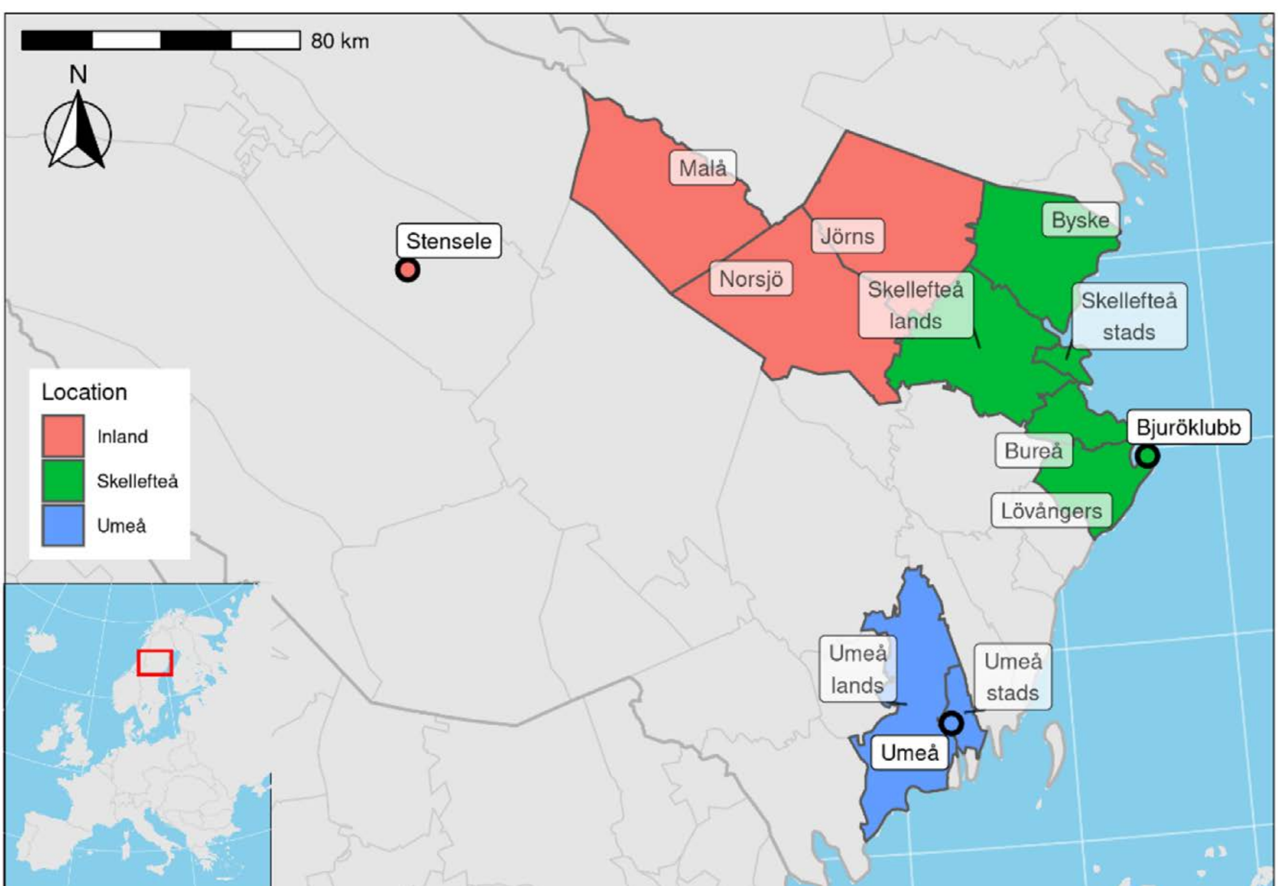

Figure 1. Study locations and their closest weather stations (marked circles).

lowest mortality temperature, the pattern was more linear, with an increase in the IRR at higher temperatures. However, for all estimated IRRs in Figure 2, the confidence intervals were wide, indicating no clear effect of temperature on stillbirths. Overall, the adjusted IRR in Figure 2 followed the unadjusted relation between temperature stillbirth rates (Figure A9 in Appendix; http://links.lww.com/EE/A164). The next model (M2) shows the IRR stratified by extended winter and summer season.

For the extended winter season (October to March), there were no clear effects from high or low temperatures (Figure 3, M2). For the extended summer season (April to September), there were notable cold effects. For mean temperatures of around −10°C during the 7 days prior birth, the IRR was 2.35 (CI 1.34, 4.15), compared to the temperature with the lowest mortality of +14°C. The linear assumptions in these models were confirmed by sensitivity analyses allowing the stillbirth-temperature relation to be nonlinear (Figure A5 in Appendix; http://links.lww.com/EE/A164). The largest effects of low temperature during the summer were observed during the time-period of 1880–1899, and of higher temperature during the period 1900–1929, although the confidence intervals were large (Figure A2 in Appendix; http://links.lww.com/EE/A164). Even above the lowest mortality temperature, the risk of stillbirth appeared to increase, with an IRR of 1.21 (CI 0.90, 1.64) at +20°C.

For both sexes, the IRR increased as temperatures fell during the summer season (M3, Figure 4). The IRR for girls was 2.01 (CI 0.83, 4.85) at temperatures of −10°C, compared to the lowest mortality temperature of +14°C, and among boys, the corresponding IRR was 2.69 (CI 1.28, 5.66). An adverse effect from higher temperature during the summer season was only observed for boys with an IRR of 2.41 (CI 1.13, 5.15) at temperatures of +25°C compared to +14°C. There was no clear cold effect during the winter season for either sex.

Discussion

Infant mortality has been used as a customary measure of health transformations and public health status in a population, while stillbirths have received less attention in historical analyses.[35]

This study, based on a large population sample in northern Sweden during 1880–1950, revealed that stillbirth rates did not decrease continuously over the study period, but had a peak in the 1930s, in particular among boys. Trends differed also by region and were characterized by substantial year-to-year variation in stillbirths.

In general, stillbirth risk was highest in spring and in the extended summer season (April to September), although the difference to other seasons was small. Similarly, a Finnish study by Eriksson and Fällman[18] showed an increased stillbirth risk during spring, but also during autumn. Also for Swedish inland settlers in the 1800s, we previously found slightly lower perinatal mortality (stillbirths and deaths in the first week of life) in winter than in summer.[20,21] It has been argued that the workload in agrarian communities is higher in the warmer period than in winter, leading to higher risks of perinatal deaths.

Our findings did not reveal any clear effect of temperature on stillbirths across the entire year, unlike, e.g., Bruckner et al,[8] who showed a strong cold effect on birth outcomes in Uppsala, Sweden in the early 1900s. Surprisingly, during the extended winter season (October to March), no association of cold was found. As supported by our previous studies on climate vulnerability of the unborn,[20,36,37] the fetus seems more vulnerable to temperature during spring to autumn than during other seasons. Previously, we also found among settlers in the more remote inland during the 19th century that perinatal mortality risk in winter was not affected by either high or low temperature in the month preceding birth.[20] This might be due to the fact that farmers generally spent more time indoors in the cold period and were thus less exposed to temperature extremes. On the contrary, low ambient temperature was likely linked to high levels of indoor air pollution from biofuel sources, and therefore might have increased the risk of adverse birth outcomes, as demonstrated by a number of studies in low-income settings.[38–40] However, these health effects (temperature impacts on birth outcomes mediated by indoor pollution) would occur at longer time lags than investigated in the present study.

The seasonal variations in warm and cold effects might here be explained by different seasonal adaptation strategies to extreme temperature exposure. Living in a subarctic environment with long and cold winters would have made the population more prepared for extreme cold during the winter compared to the summer season. Unlike in winter, agricultural work was intense during the extended summer season, particularly during the harvest in August and September. Pregnant women (including those at a later stage of pregnancy) might have had limited control over their workload and exposure to

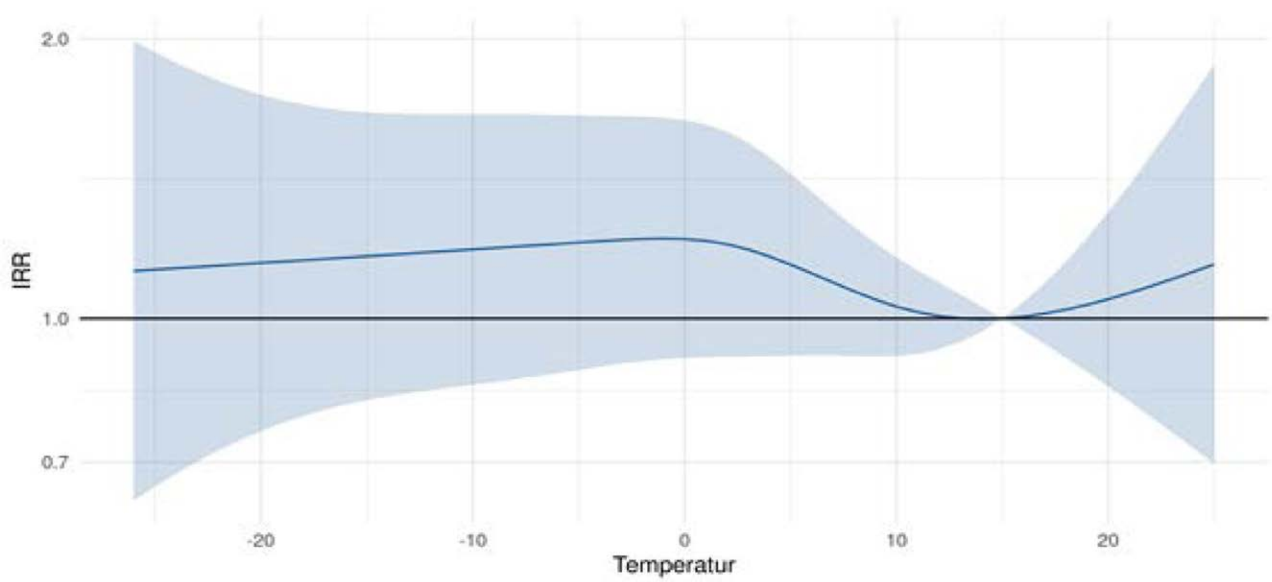

Figure 2. M1: Incidence risk ratios (IRR) of stillbirth death with 95% confidence intervals, by temperature exposure, adjusted for seasonality and time-trends, 1880–1950. See Table A2; http://links.lww.com/EE/A164 for the IRR and confidence interval values at specific temperature points.

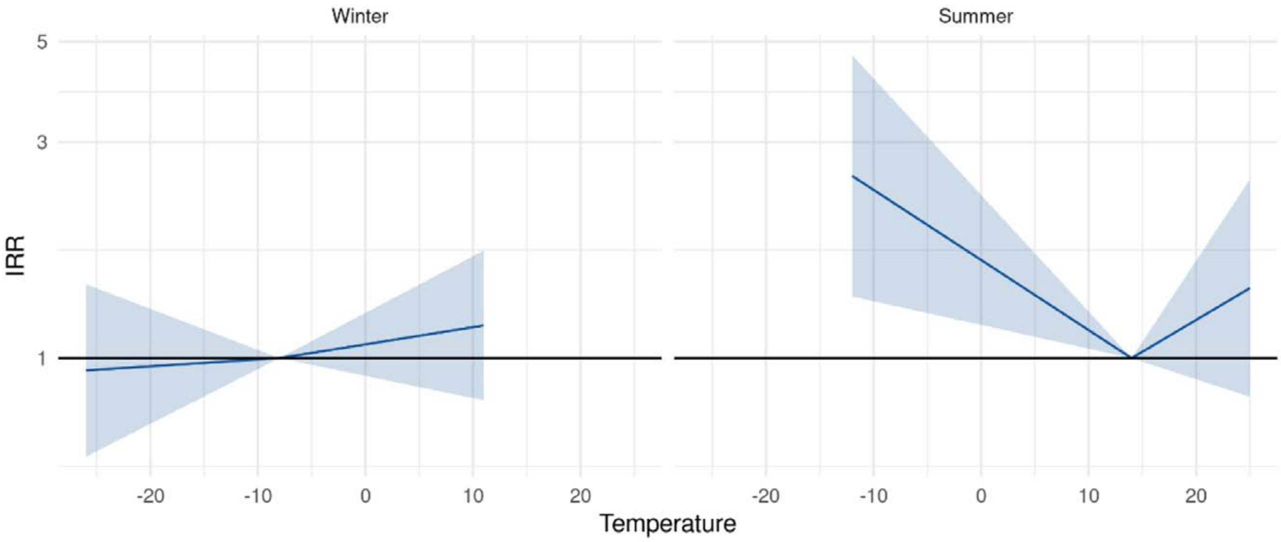

Figure 3. M2, incidence risk ratios (IRR) of stillbirth death with 95% confidence intervals, by temperature exposure where stillbirths were observed, stratified by extended season, 1880–1950. See Table A3; http://links.lww.com/EE/A164 for the IRR and confidence interval values at specific temperature points. Extended winter season: October to March; extended summer season: April to September.

both cold and heat, contributing to an increased stillbirth risk. Even smaller deviations from the lowest mortality temperature during the extended summer season appeared to have had an effect on survival. Relating our findings to a systematic review on the association between adverse temperature and stillbirth risks,[41] we found similar results, e.g., that the stillbirth risk increased below +15°C and above +23.4°C, but here only seen during the extended summer season and among male fetus.

Stillbirth risk was substantially higher among boys than girls, as was their climate vulnerability in summer. Neither sex appeared to be affected by high or low temperature in the extended winter season. That the male fetus has higher mortality has been shown in a number of studies among historical populations, although the sex ratio in stillbirth rates has decreased over time.[22,42-44] Today, stillbirth risk is approximately 10% higher among males than females, irrespective of the country of birth or socioeconomic position.[43] Male fetuses seem more vulnerable to a range of environmental stressors experienced by their mothers compared to female fetus, while the underlying biological causes to these sex differences are still unknown.[4] In our study, we found boys to be more climate vulnerable during summer, with their stillbirth risk increasing more steeply above than below the lowest mortality point of +14°C. A weaker effect from cold, but no effect from heat during the summer, was seen

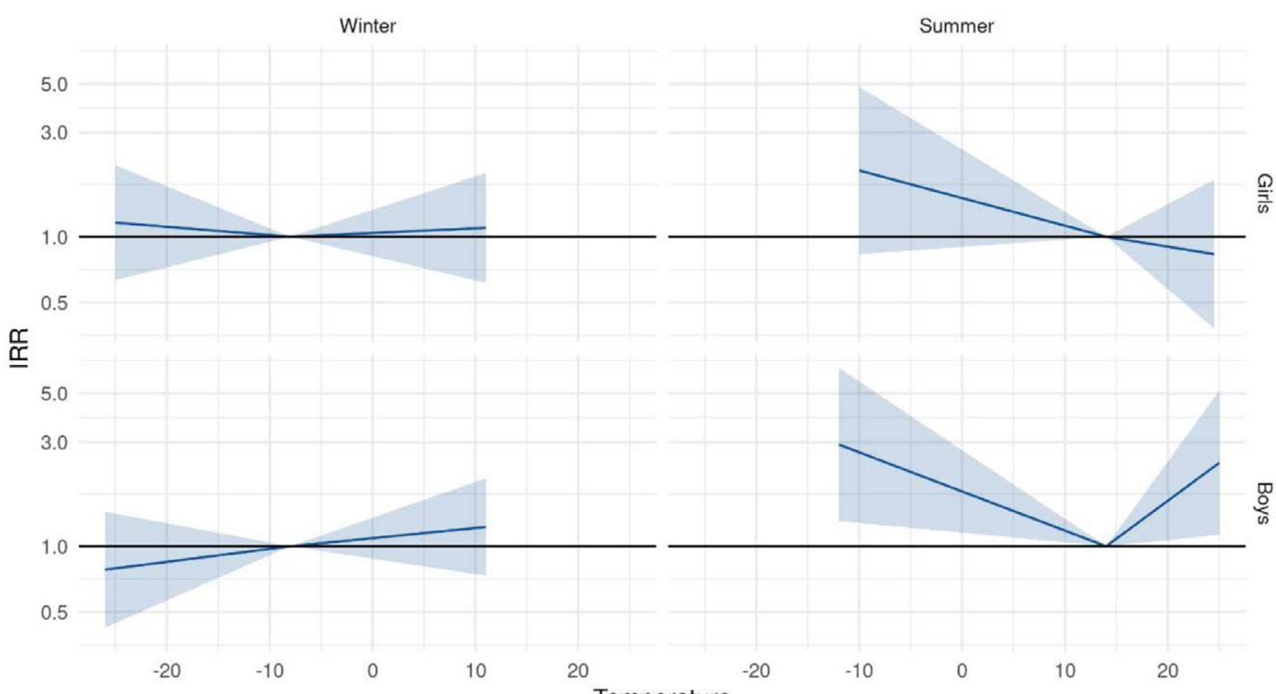

Figure 4. M3, incidence risk ratios (IRR) of stillbirth death with 95% confidence intervals, by temperature exposure where stillbirths were observed, stratified by sex, 1880–1950. See Table A4; http://links.lww.com/EE/A164 for the IRR and confidence interval values at specific temperature points. Extended winter season: October to March; extended summer season: April to September.

among girls. In contemporary studies, male fetuses have been shown to be more vulnerable to ambient heat than their female counterparts,[4,45] which is the case even for new-born boys, due to their overall developmental disadvantage resulting in higher risks of preterm birth and low birth weight.[36]

The uneven decline in stillbirth rates between 1880 and 1950 indicates that contextual factors such as health care access and urbanization are important drivers of the vulnerability of the unborn child and interact with biological factors such as antepartum hemorrhage, infections, and placental abruption.[46] These contextual factors might have also contributed to variations in the climate vulnerability of our study population. We found that cold-related stillbirth risk in summer was greatest in the first two and last two decades of the study period, and lowest between 1900 and 1929. During this period, on the contrary, heat-related stillbirth risk was higher than in the decades before and after. The early decades of the 1900s were characterized by urbanization and poor housing conditions in the towns in our study region. Contemporary studies, e.g. from Nepal[47] and Zambia,[48] hint at unclean water and poor sanitation as risk factors for stillbirths. In Swedish urban settlements in the early 1900s, high ambient temperature might have facilitated contamination of water sources in the warmer season, thereby increasing the risk of adverse pregnancy outcomes. In the decades to follow, sanitation in Skellefteå and Umeå improved, which might have led to a decline in heat-related stillbirths.

We found the highest heat-related risks in the period 1900–1929. Possible risk factors that might have contributed to this increased risk are maternal pregnancy conditions, occupational health, nutritional status, and infectious diseases.[9] For example, a combination of frequent pregnancies, food shortage in late spring, hard workload during harvest season, and widespread diseases of tuberculosis and the Spanish Flu could have made pregnant women more vulnerable to high ambient temperature in the first decades of the 20th century.

The comparatively high stillbirth rates found between 1925 and 1940 were observed mainly in the Skellefteå area, hinting at the importance of local contextual and environmental factors. From the 1920s onwards, the Skellefteå area underwent a major population growth related to the expansion of mines and smelter plants. The role of heavy metals and other toxic substances for the health of smelter workers and their offspring have been highlighted in a number of studies.[49–54] It is however still unclear whether adverse birth outcomes (spontaneous abortions, perinatal, and neonatal mortality) are increased in communities living near smelting plants.[49,50,53]

Even in contemporary societies, temperature can pose a risk factor for the unborn.[41] In Canada, stillbirths due to maternal complications were associated with both high and low temperature.[5] This indicates a general thermo-physiological pressure on the fetus contributing to risk of death at higher gestational ages. The biological mechanisms of ambient temperature on stillbirths remain unclear, including potential effect modifiers affecting maternal body temperature regulations and health during warm and cold extreme exposure.[41]

Reasons for the lack of historical studies on stillbirths include the absence of vital data and reliable birth registers, but also obstacles concerning the identification and registration of deaths as stillbirths or early neonatal deaths (having signs of life at birth). Unlike many other European countries, Sweden has an unbroken, high-quality registration system of stillbirths from 1750 to today.[44] The establishment of the governmental agency Statistics Sweden in 1860 implied that parish registrations were centrally controlled, which further strengthened the homogenization and high quality of Swedish data. By accessing this register data, in combination with long-term weather records from the study region, we were able to study the association between ambient temperature and fetal health, and to compare the climate vulnerabilities of the unborn between sexes and across time.

Limitations

The effects of low and high temperatures were evident in the extended summer season, which stretched, however, from late spring into autumn. Analyses for shorter time windows would have been preferable (also because the stillbirth risk in spring was generally higher) but were unfeasible due to low stillbirth counts. Available data also did not include details about the pregnancy and birth. Today, about one half of stillbirths occur during the antepartum period, and one half during labor.[55] In this retrospective study, information about gestational age or whether fetal death occurred before or during labor was lacking, which limited our analyses on the more exact timing of temperature effects on stillbirth risk. Other limitations of this study include the restriction to short-term temperature effects, and the lack of control for indoor and outdoor air pollution, which might have acted as confounders or effect modifiers, in particular for more long-term effects before birth.

Conclusion

This study on fetal climate vulnerability was conducted in a predominantly rural, subarctic region progressing from an agricultural to an industrializing society with improving maternal health care access. Our findings demonstrated that even in a cold climate like Sweden, high temperature can be a health hazard for humans, including male fetuses during summer. Low temperature, on the contrary, posed an increased risk for stillbirth only in the warmer season, especially among boys. This implies that studies need to consider seasonal differences in the temperature-health link, depending on the local climate and living and working conditions.

Globally, stillbirths remain a neglected issue, where the majority are preventable through higher access to antenatal, maternal, and obstetric health care.[55] In many low- and middle-income countries, the number and gestational age of stillborn children are not well documented, which further impedes monitoring and reduction of stillbirths.[56] Our study showed that Swedish stillbirth rates decreased in accordance with the introduction of large-scale maternal healthcare measures. Time trends in fetal climate vulnerability appear, however, to be more complex.

Insights into differential effects of temperature by season, sex, and socio-economic development might be useful to improve the health status of mothers and their fetus in resource-poor settings all over the world.

Additional considerations regarding the choice of models

Although the use of linear threshold models could be biased by the selection of a reference temperature, sensitivity analyses allowing for a full nonlinear relation support the linear-threshold assumption (M6, Figure A5). Furthermore, based on previous studies, we assumed that ambient temperature affected stillbirths up to a week after exposure. Sensitivity analyses using daily exposures were conducted, specifying the daily exposure over the past 14 days as a nonlinear cubic spline, M7 Figure A6 in Appendix; http://links.lww.com/EE/A164. Overall, vulnerability to high and low temperatures was observed up to 7 days before birth.

Conflicts of interest statement

The authors declare that they have no conflicts of interest with regard to the content of this report.

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