Time series analysis shows no influence of ambient temperature on the human sex ratio at birth in New Zealand

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Abstract

Background: The Secondary Sex Ratio (SSR) of humans has been shown to be male biased in temperate climates around the world. Given that fluctuations in ambient temperature have previously been shown to affect sex allocation in humans, we examined the hypothesis that ambient temperature predicts fluctuations in the SSR in New Zealand.

Methodology/Principal Findings: We tested three main hypotheses using time series analyses. Firstly, we used historical annual data in New Zealand spanning 1876-2009 to test for a positive effect of ambient temperature on the SSR. The proportion of males born ranged by 3.115%, from 0.504 to 0.520, but no significant relationship was observed between sex ratio and mean annual temperature in the concurrent or previous years. Secondly, we examined whether changes in annual ambient temperature are negatively related to the sex ratio of stillbirths from 1929-2009 and whether the stillbirth sex ratio negatively affects the SSR. We found no evidence that fewer male stillbirths occurred during warmer concurrent or previous years, though a declining trend in the stillbirth sex ratio was observed throughout the data. Thirdly, we tested whether seasonal ambient temperatures, or deviations from those seasonal patterns, were positively related to the SSR using monthly data from 1980-2009. Patterns of male and female births are seasonal, but very similar throughout the year, resulting in a non-seasonal SSR. No cross correlations between SSR and lags of temperature were significant, and the estimates displayed a similar pattern to those between a simulated time series of independent, zero-mean Gaussian observations and lags of temperature.

Conclusions: Results showed, across all hypotheses under examination, that ambient temperatures were not related to the SSR or the stillbirth sex ratio in New Zealand. While there is evidence that temperature may influence human SSR in temperate climates elsewhere, such effects of temperature are not universal.

Keywords: Ambient temperature; seasonal variation; secondary sex ratio; stress; temperate climates; temperature anomalies; time series

Introduction

The global secondary sex ratio (SSR: the ratio of males born: total births) in humans is currently estimated at 0.517 (Central Intelligence Agency, 2010). This male bias in the SSR deviates from the 1:1 sex ratio predicted by natural selection (Fisher, 1930) and has prompted a large body of research investigating the causal mechanisms underpinning this anomaly. Natural selection may have favoured mechanisms in women that select *in utero* for the offspring that will be most reproductively successful in given environmental circumstances (Trivers and Willard, 1973). Political unrest, natural disasters and maternal stress are among a long list of traits suggested to lower the male bias in human sex ratios (James, 2010; Navara, 2010), whereas during the First and Second World Wars in Europe, a more male-biased SSR has been documented (James, 2009).

Climatic differences across populations, as well as fluctuations in rainfall and ambient temperature, may also affect the human SSR (McLachlan and Storey, 2003). Indeed, both increases and decreases in ambient temperature have been shown to have an effect on mortality (Basu and Samet, 2002; Lerchl, 1998a; Young and Mäkinen, 2010). Thus, if climate causes a physiological stress and plays a determining role in sex allocation in humans, it may also affect the SSR if mothers are exposed to shifts in temperature during gestation (Catalano et al., 2008). According to evolutionary theory (McLachlan and Storey, 2003; Trivers and Willard, 1973), there should be fewer males born during stressful colder periods, as a weaker male would not survive to reproduce where a healthy female might, with more males expected to be born during warmer periods.

The hypothesis that mean annual ambient temperature is related to the SSR has been tested in several studies. Globally the SSR was shown to be significantly less male-biased at tropical latitudes in comparison to temperate and subarctic latitudes (Navara, 2009). However, studies conducted on a smaller scale in Finland and elsewhere in Scandinavia using long-term data sets and time-series analyses have found that more males are born in years with higher mean annual temperatures (Catalano *et al.*, 2008; Helle *et al.*, 2008; Helle *et al.*, 2009), which suggests that mean ambient temperature affects maternal condition and influences the SSR. Using annual birth records it is possible to identify patterns in the SSR and potential relationships with environmental factors, such as ambient temperature. However, human conceptions also occur seasonally (Cagnacci et al., 2003; Lerchl 1998b; Rizzi & Dalla-Zuanna, 2007), prompting the need to investigate any cyclic patterns in SSR using seasonal or monthly data, in order to further identify any adaptive mechanisms of temperature and sex allocation in human beings (Lerchl, 1999).

Given that the SSR has been shown to be male biased in temperate climates around the world (Navara, 2009), and fluctuations in ambient temperature may affect sex allocation in humans (Catalano *et al.*, 2008; Helle *et al.*, 2008; McLachlan and Storey, 2003), we examined whether ambient temperature predicts fluctuations in the SSR in New Zealand. Three separate analyses were conducted, each employing time-series methods. Firstly, we tested the hypothesis that there should be a positive relationship between mean annual ambient temperature and the proportion of males born (Catalano *et al.*, 2008; Helle *et al.*, 2008; Helle *et al.*, 2009) using historical data spanning 1876-2009. Secondly, we tested the hypothesis that foetal survivability may be influenced by changes in mean annual ambient temperature and may influence the SSR (Basu *et al.*, 2010; Catalano *et al.*, 2008) [11,19] using annual data on the sex ratio of stillbirths from 1929-2009. Thirdly, we tested the hypothesis that seasonal variation in ambient temperature at the time of conception is related to the SSR (Lerchl, 1999) using monthly data from 1980-2009. We also tested for the effect of extreme temperatures on the SSR using a temperature anomaly series (Lerchl, 1999) and additionally we considered two simpler hypotheses: that the monthly numbers of births, and the monthly SSR vary in a seasonal manner (Lerchl, 1998b).

Materials and Methods

Historically, in New Zealand detailed demographic and vital statistics of European settlers were collected in annual census reports from the mid-1800s by the national statistical office, Statistics New Zealand. From 1925 onwards, all ethnic groups were reported. Statistics New Zealand provided us with annual numbers of recorded births for the period 1876-2009, which ranged from a minimum of 16168 in 1876 to a maximum of 65476 in 1961. The numbers of males and females born each year were used to calculate the annual SSRs from 1876 to 2009. We also calculated the sex ratio of stillborn babies, defined by Statistics New Zealand as a late foetal loss (the current definition being a birth after the 20th week of gestation or a birth weight of at least 400g). Annual data on stillbirths were first collected by Statistics New Zealand in 1929, limiting our analyses incorporating the sex ratio of stillbirths to the years 1929-2009. Numbers of stillborn babies ranged from a minimum of 169 in 1973 to a maximum of 971 in 1941. Data on monthly SSR (but not stillbirths) were available from Statistics New Zealand from 1980 to 2009, which we used for a seasonal analysis of the SSR.

To obtain a composite measure of temperature in ˚C for New Zealand, we used data collected by the National Institute of Water and Atmospheric Research (NIWA) at multiple sites from seven locations, three on the North Island (Wellington, Auckland, Masterton) and four from the South Island (Hokitika, Nelson, Lincoln, Dunedin). NIWA is a New Zealand government-owned Crown Research Institute. The seven locations were selected by NIWA as they provide a representative geographical spread across New Zealand and have reliable historical records. The temperature data across these sites were merged by NIWA using a standardized methodology for New Zealand (NIWA, 2010; Rhoades and Salinger, 1993) and incorporated into our analyses for the first two hypotheses.

For our analysis on the possible effects of seasonal changes in ambient temperature, six of the seven NIWA sites were used to calculate monthly ambient temperature for New Zealand for the period 1980-2009. The weather station at Hokitika was not included on the recommendation of NIWA, due to the difficulty in constructing a consistent monthly data set for the time period. The average across the six weather stations was calculated in order to generate a composite measure of ambient temperature for each month of the year for the time period 1980-2009. Following Lerchl (1999), we also calculated a temperature anomaly series, by subtracting from each observed monthly temperature the relevant monthly average temperature, calculated for each of the 12 months of the year across the 30 years. The temperature anomaly series allows us to investigate the effect of unusually warm or cold months on the SSR, compared to the average for that time of year.

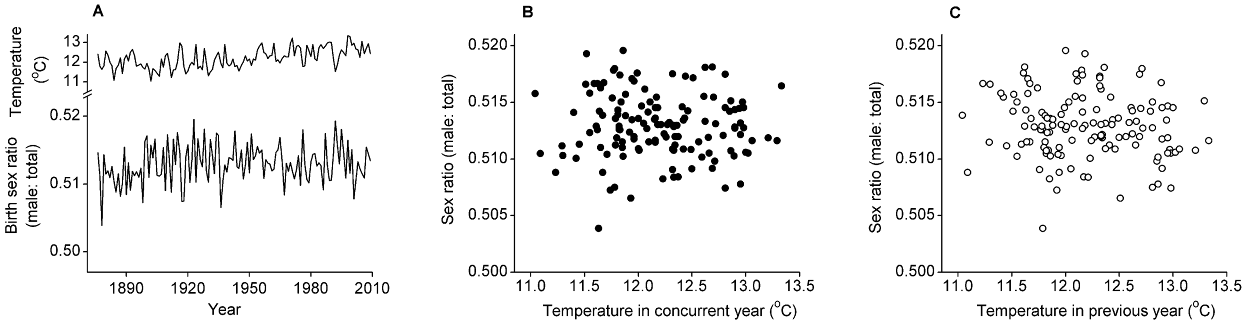
We used transfer function (ARIMA) models (Box *et al.*, 2008) to estimate the dynamic effects on the SSR of temperature and the sex ratio of stillbirths, following the statistical analyses described by Catalano *et al.* (2008). In addition, in order to identify any unusual outlying observations or structural changes that are best modelled explicitly as functions of time, we used an intervention analysis approach (Box and Tiao, 1975; Tsay, 1986). Models were tested to ensure a lack of residual autocorrelation using the Ljung-Box portmanteau statistic (Ljung and Box, 1978); all models discussed below had no residual structure ($p \geq 0.319$). Computations used SPSS (SPSS, 2009).

Results

For our first hypothesis, the mean annual temperature ranged from 11.04-13.33ºC over the period 1876-2009. The proportion of males born ranged by 3.115%, from 0.504 in 1878 to 0.520 in 1923 (Fig. 1). We found no significant relationship between sex ratio and the mean annual temperature in the concurrent or previous years ($p \geq 0.187$; Table 1).

For the second hypothesis, we re-analysed the subset of SSR data for which we had stillbirth information (1929-2009). We found no significant relationship between SSR and the mean annual temperature in the concurrent or previous years ($p \geq 0.211$; Table 2), neither did the sex ratio of stillbirth babies in the concurrent or previous years have any significant effect on the SSR ($p \geq 0.295$; Table 2).

Figure 1. Annual SSR and mean ambient temperature



A. The SSR from 1876-2009 and the corresponding mean annual ambient temperature in ˚C. The SSR in relation to mean annual ambient temperature is also shown for the B, concurrent and C, previous years.

Table 1. The effects of temperature during the concurrent and previous years on the annual SSR from 1876-2009*.

	β (±s.e.)	*t*	*p*
Constant	0.520 (±0.007)	77.02	< 0.001
Temperature	1.8×10^{-4} (±0.001)	0.311	0.756
Temperature $_{t-1}$	0.001 (±0.001)	1.326	0.187

*Selected model required no ARIMA parameters, since there was no residual autocorrelation: Ljung-Box $p = 0.319$. Model $R^2 = 0.015$.

Table 2. The effects of temperature and stillbirth sex ratio during the concurrent and previous years on the annual SSR from 1929-2009*.

	β (±s.e.)	*t*	*P*
Constant	0.534 (±0.015)	36.65	< 0.001
Temperature	-0.001 (±0.001)	-0.796	0.428
Temperature $_{t-1}$	0.001 (±0.001)	1.261	0.211
Stillbirths	-0.013 (±0.012)	-1.054	0.295
Stillbirths $_{t-1}$	-0.008 (±0.012)	-0.707	0.482

*Selected model required no ARIMA parameters, since there was no residual autocorrelation: Ljung-Box $p = 0.564$. Model $R^2 = 0.067$.

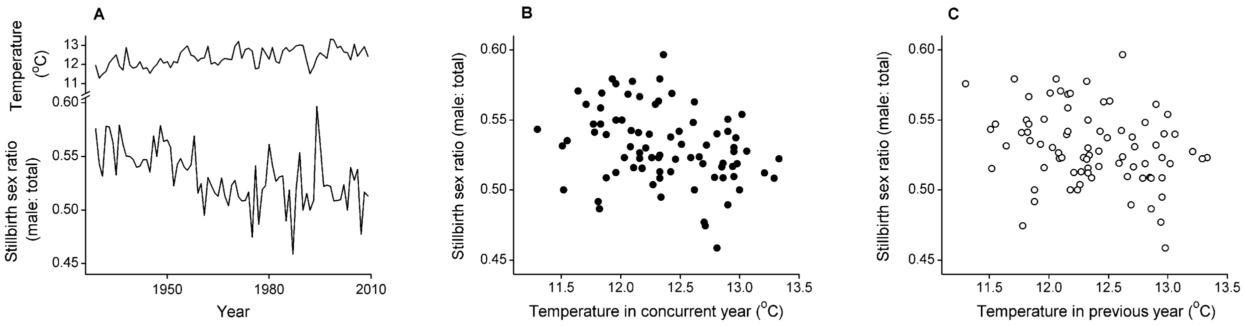
Table 3. The effects of temperature during the concurrent and previous years on the stillbirth sex ratio from 1929-2009*.

	β (±s.e.)	*t*	*P*
Constant	0.590 (±0.089)	6.618	< 0.001
Temperature	-0.002 (±0.006)	-0.257	0.798
Temperature $_{t-1}$	0.001 (±0.007)	0.199	0.843
Outliers/Structural change			
1994 (Additive)	0.080 (±0.022)	3.706	< 0.001
1929 (Local Trend)	-5.9×10^{-4} ($\pm 1.3 \times 10^{-4}$)	-4.414	< 0.001

*Selected model required no ARIMA parameters, since there was no residual autocorrelation: Ljung-Box $p = 0.873$. Model $R^2 = 0.387$.

We also found no evidence that fewer male stillbirths occurred during warmer concurrent or previous years ($p \geq 0.798$; Table 3). A declining trend in the stillbirth sex ratio was observed throughout the data (slope= $-5.9\times10^{-4} \pm 1.3\times10^{-4}$, $p < 0.001$; Fig. 2). A significant positive outlier occurred in 1994 (0.080 ± 0.022, $p < 0.001$), which was when the highest sex ratio of 0.596 was recorded.

Figure 2. Annual stillbirths sex ratio and mean ambient temperature



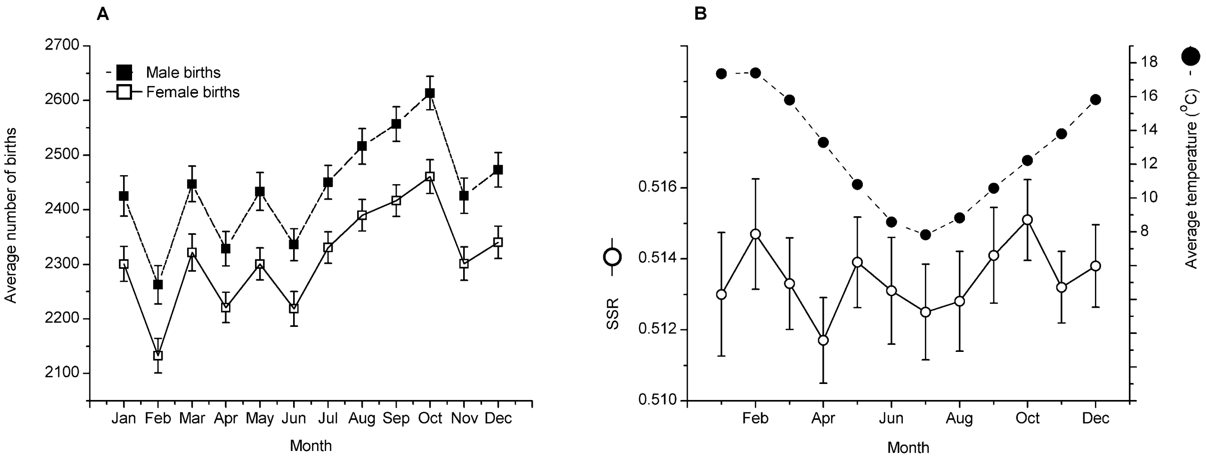
A. The ratio of male stillbirths to the total number of stillbirths from 1929-2009 and the corresponding mean annual ambient temperature in ˚C. The sex ratio of stillbirths in relation to mean annual ambient temperature is also shown for the B, concurrent and C, previous years.

In fact the annual SSR series shows no temporal structure and behaves like random noise: lag-1 autocorrelation = -0.037, $p = 0.667$; Ljung-Box statistic = 17.081 (at 16 lags), $p = 0.380$. In contrast, annual temperature is strongly positively correlated: lag-1 autocorrelation = 0.555, $p < 0.001$; Ljung-Box statistic = 181.630 (at 16 lags), $p < 0.001$.

For our third hypothesis, following Lerchl (1998b, 1999), we tested whether monthly ambient temperatures, or deviations from those seasonal patterns (i.e. extreme temperatures), were positively related to the monthly SSR over the period 1980-2009. We also tested whether monthly numbers of births, and the monthly SSR, vary in a seasonal manner.

As Figure 3A shows, there is a seasonal pattern in the number of births with more males and more females born in the months of August-October than at any other time of year. The patterns of male and female births are very similar throughout the year though, reflected in the lack of any seasonal pattern in the SSR (Fig. 3B). As expected, mean temperature shows a very marked seasonal pattern (Fig. 3B).

Figure 3. Monthly mean number of births, mean SSR and mean temperature

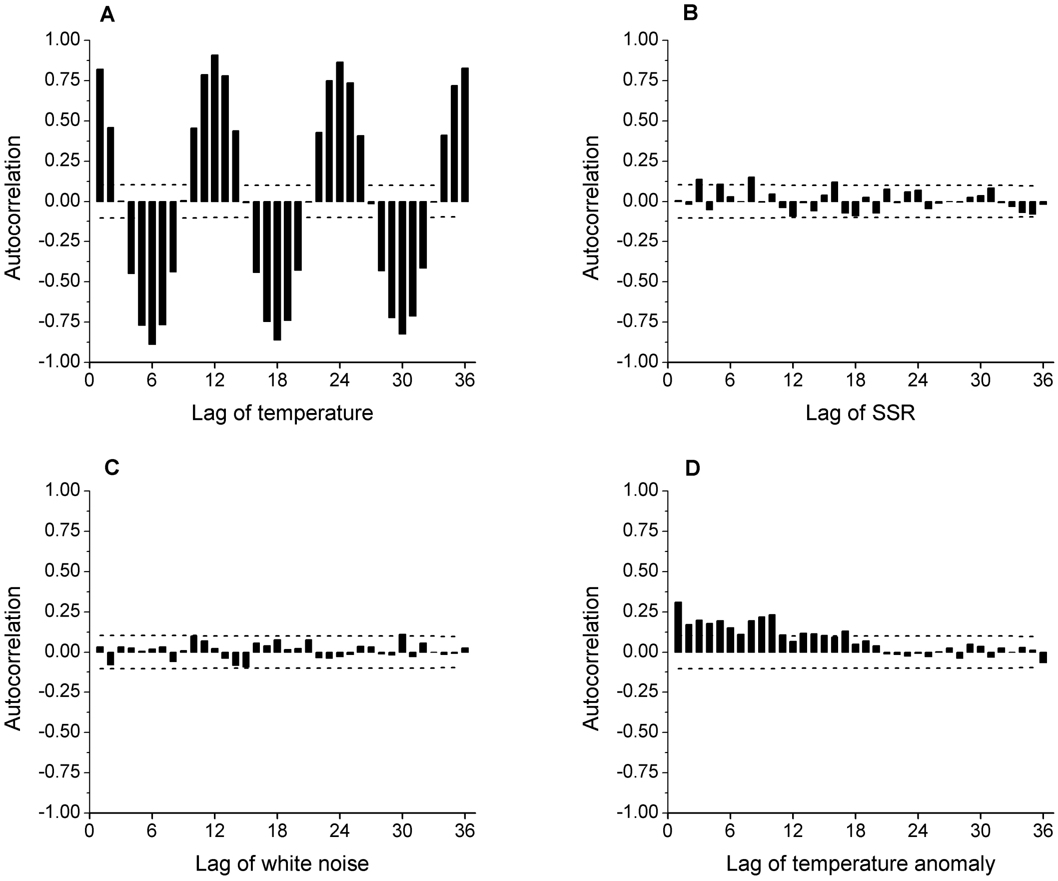


A. The average numbers of male and female births (± 1 standard error) in each month of the year, averaged over 1980-2009 (*n* = 30). B. Average SSR ± 1 standard error (left axis) and average temperature ± 1 standard error (right axis), averaged over 1980-2009. Temperature is clearly seasonal, while SSR is not.

These general impressions are supported by the autocorrelation functions, to 36 lags, of temperature and SSR (Figs. 4A, 4B). Temperatures 12 months apart (and 24, 36, etc.) are highly, positively correlated, while temperatures 6, 18, 30 months apart are highly, negatively correlated. In contrast lags of SSR show almost no significant correlations, with only marginal significance at lags 3, 8 and 16. The sizes of the estimated SSR autocorrelations are similar to those of a simulated time series of 360 independent, zero-mean Gaussian observations, or white noise (Fig. 4C). As expected following the positive association seen in the annual temperature series, the temperature anomaly series shows modest (significant) positive correlations, extending for approximately 18 lags (Fig. 4D).

The cross correlations between SSR and lags of temperature (to lag 36) are shown in Figure 5A, following the approach of Lerchl (1999). All correlations are small in absolute size, with none statistically significant. There is a cyclical pattern to the estimated cross correlations, yet this is to be expected (e.g. Box *et al.*, 2008, Chapter 12) because of the very pronounced cyclical pattern in the autocorrelation function of temperature (Fig. 4A). To illustrate this further, the cross correlations between a simulated independent white noise series and lags of temperature (to lag 36) are shown in Figure 5B, which also display a cyclical pattern, with correlations of similar magnitude to those in Figure 5A.

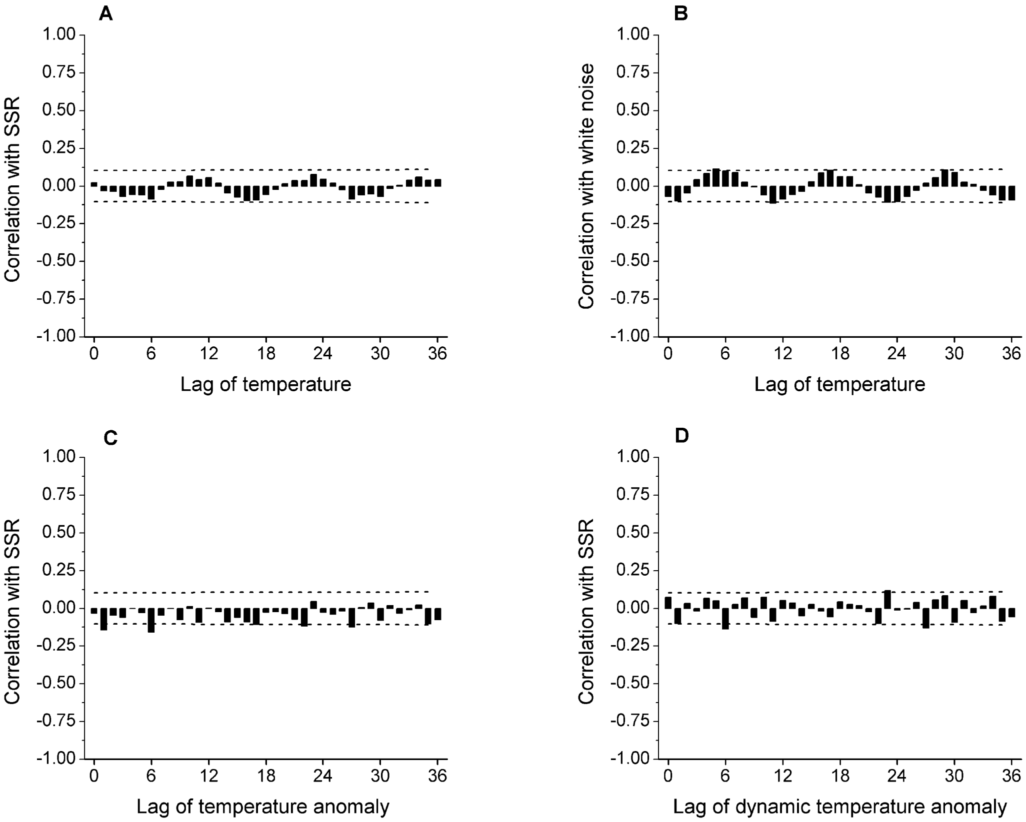
Figure 4. Monthly autocorrelations



Sample autocorrelations, to 36 lags, of: A, monthly NZ temperature (1980-2009); B, monthly NZ SSR (1980-2009); C, a simulated white noise time series of $n = 360$ independent observations; D, monthly NZ temperature anomaly (1980-2009). Dashed lines show 95% confidence interval limits for true correlations of zero; estimates outside these limits are significantly different from zero with $p < 0.05$.

The cross correlations between SSR and lags of the temperature anomaly series (to lag 36) are shown in Figure 5C. These cross correlations are almost all not significant, with marginally significant negative correlations only at lags 1, 6, 22 and 27.There are certainly no significant positive correlations at any lag, in contrast to the findings of Lerchl (1999). However, a feature of the correlations presented in Figure 5C is that they are almost all negative, which seems somewhat unexpected. The reason is that the method used to construct the anomaly series, following Lerchl (1999), takes a global average across the thirty years in order to identify departures from ‘trend’. However, time series trends are more appropriately modelled dynamically using decomposition methods (Findley *et al.*, 1998; Harvey, 1990; Makridakis *et* *al.*, 1998), and an alternative temperature anomaly series can be constructed using departures from a dynamic seasonal pattern, following estimation using a centred 12-point moving average (e.g., Makridakis *et al.*, 1998). The cross correlations between SSR and lags of the dynamic temperature anomaly series (to lag 36) are shown in Figure 5D. As before, these cross correlations are almost all not significant, with marginally significant correlations only at lags 6, 23 and 27. Now though, similar numbers of positive and negative correlations appear. The overall impression is consistent with that from Figure 5C: there are no significant positive correlations at lags just preceding the time of conception, in contrast to the findings of Lerchl (1999). Thus, neither seasonal variations in temperature nor temperature anomalies (extremes) positively influence the SSR in New Zealand.

Figure 5. Monthly cross correlations



Sample cross correlations, to 36 lags, of: A, monthly SSR with temperature (1980-2009); B, 360 simulated independent white noise observations with monthly temperature (1980-2009); C, monthly SSR with temperature anomaly (1980-2009); D, monthly SSR with dynamic temperature anomaly (1980-2009). Dashed lines show 95% confidence interval limits for true correlations of zero; estimates outside these limits are significantly different from zero with $p < 0.05$.

Discussion

This study showed that the impact of concurrent and previous year mean annual ambient temperatures on the secondary sex ratio (SSR) in New Zealand (NZ) was not statistically significant from 1876-2009. Changes in the SSR from 1929-2009 were not related to changes in the concurrent or previous year sex ratios of stillbirths. In addition, changes in mean annual temperature had no effect on the stillbirth sex ratio. Finally, while we did detect a seasonal pattern in the number of births from 1980 to 2009, the SSR did not display a seasonal pattern and monthly fluctuations in ambient temperature were unrelated to the SSR. Further, monthly temperature anomalies (extremes) did not affect the SSR. Our results therefore do not support the temperature dependent sex allocation hypothesis for people living in NZ.

The results from tests of our first hypothesis differ from other studies in which time-series analyses were used to explore the relationship between the SSR and fluctuations in mean annual ambient temperature. Studies conducted in Finland and elsewhere in Scandinavia have found that more males are born in warmer years (Catalano *et al.*, 2008; Helle *et al.*, 2008) and increases in temperature increased the likelihood of a male foetus surviving (Catalano *et al.*, 2008). However, results from studies testing for associations between temperature and the SSR conducted on a broader global scale have been mixed. Navara (2009) used global data on the SSR from 202 countries from 1997-2006 and found that the SSR was significantly less male-biased at tropical latitudes than in temperate and subarctic latitudes. In African countries and among women of sub-Saharan African descent, it has been shown that the SSR is less male biased than among non-African women (Garenne, 2002; Kaba, 2008). In warmer climates in Europe more males were born; however, this trend was not observed in North American cultures (Grech *et al.*, 2002). Our results for New Zealand follow the general global pattern of male-bias in the SSR that have been observed in other temperate climates (Navara, 2009). However, we found no effects on the SSR of fluctuations in ambient temperature between years. Therefore we cannot provide further confirmation of findings in the published literature for an effect of ambient temperature on the SSR.

We did detect a decline in the number of stillbirths from 1929-2009, which may reflect improvements in pre-natal healthcare in New Zealand that helped reduce gestational stresses. However, time-series analyses did not reveal any relationships between the sex ratio of stillbirths and mean annual ambient temperature. This is in contrast to a previous study comparing data from Denmark, Finland, Norway and Sweden, where increases in ambient temperature significantly increased the SSR but reduced the life-span of the male cohort at one year of age, suggesting that fluctuations in ambient temperature can induce stress during gestation, resulting in the loss of male foetuses (Catalano et al., 2008). It is important to note that changes in definitions of a stillbirth from 1995 onwards have increased the number of stillbirths that have been logged in NZ. Prior to 1995, a stillbirth was only logged if the miscarriage occurred after 28 weeks. From 1995 onwards, the definition of a stillbirth was changed to include all miscarriages from 20 weeks of gestation onwards or a foetal body weight of at least 400g. However, the change in stillbirth definition in New Zealand had no effect on the sex ratio of stillbirths.

Our study incorporated a similar geographic range and range of fluctuations in temperature as the studies which have found a significant relationship between annual SSR and mean temperature (Catalano *et al.*, 2008; Helle *et al.*, 2008; Helle *et al.*, 2009). Nevertheless, our use of a composite measure of annual ambient temperature and SSR may hide or mask any possible seasonal effects of climate on sex allocation. Lerchl (1998b) analysed the SSR in Germany from 1946-1995 on a monthly basis and found a seasonal pattern in the SSR, so that the male bias increased in April to June, suggesting that conception of boys was increased during summer months (July to September). Following this analysis, Lerchl (1999) tested whether ambient temperature was linked with the seasonal SSR and identified that the temperature 10 and 11 months prior to birth was significantly positively correlated with the SSR. We did find a seasonal pattern in birth rates, with more births occurring in August to October, suggesting more conceptions occur in the summer in New Zealand (December-February). However, there was no seasonal variation in the SSR and no relationship between the SSR and the highly seasonal temperature variations, which showed clear seasonal correlations. In fact there was very little structure in the monthly SSR, so that it was similar to a simulated series of independent white noise. Therefore, as in our time-series analyses of annual SSRs and stillbirth sex ratios, we found no support for the hypothesis that seasonal variation in ambient temperature at the time of conception is related to the SSR in New Zealand.

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