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Title: An investigation into the numerical determinants of secondary sex ratio

Date: 2000

Originally published in: An abstract of this presentation appeared in *Annals of Human Biology*, 27, 642

Example citation: Lewis, S. J., & Glenn, J. (2000). An investigation into the numerical determinants of secondary sex ratio

Version of item: Author's

Available at: http://hdl.handle.net/10034/58635

An Investigation into the Numerical Determinants of Secondary Sex Ratio

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Abstract

Data from the North Wales parishes of Hawarden and Northop were found previously to show seasonality for birth rate. In keeping with values reported in other studies, an annual secondary sex ratio of 105.3% was found. This sex ratio was also found to vary throughout the year in a cyclical way with a peak occurring in late summer. When male and female birth rates were investigated separately, it was found that females showed a more pronounced cyclicity than males with the peaks for both sexes occurring in the spring. A significant negative correlation between sex ratio at birth and mean day length (hours between sunrise and sunset) of the putative month of conception was observed. Sex ratio is a useful but derived parameter and has no independent existence upon which natural selection can be said to exert a direct influence. Therefore, the behaviour of the determinants of sex ratio should not be overlooked.

Introduction

Sex ratio is the number of males with respect to the number of females within a cohort and may be divided into three types. That at the time of conception is referred to as primary sex ratio; that at birth, secondary sex ratio and that later on (a seemingly less well defined category), tertiary sex ratio. In a review of the topic, Overfield (1995) found that studies into secondary sex ratio have consistently shown an excess of males in the region of 105%, even though males have been found to produce equal numbers of X- and Y- chromosome-bearing sperm. This was, in turn, found to be markedly lower than primary sex ratio where values in excess of 120% have been noted from studies of spontaneous abortion and was suggestive of a greater fragility of the male embryo.

Although seasonality in sex ratio has attracted some attention (Nakamura, Nonaka, and Miura 1987, Nonaka, Nakamura, Miura, and Richter 1987a, Nonaka, Nakamura, Shimura, and Miura 1987b), seasonality in birth rate seems to have proved a more popular area of study. Being in the possession of data showing seasonality for birth rate (Lewis & Glenn, unpublished data), seasonality in secondary sex ratio was also investigated.

Materials and Methods

Details of births for the old Flintshire parishes of Hawarden (pronounced 'Har-den') and Northop (Figure 1), during the period 1837-1886, were obtained (by JG) from baptismal records for these parishes now kept at Clwyd Records Office, Hawarden. The information obtained consisted of date of birth and sex of each child born. Some 5,905 deliveries (accounting for 5,918 individuals - males: 3,036; females: 2,882) were recorded. Although dizygotic, different-sex twin births were easily detectable, distinguishing between mono- and dizygotic same-sex births was not possible from the available data. Thus, for purposes of investigating secondary sex ratio, the total number of males born in each month (during the entire fifty year period of study) was divided by the total number of females born in that month and expressed as a percentage, thus:

$$\frac{M_{m50}}{F_{m50}} \times 100$$

The statistical package *Regression* (Blackwell Scientific Publications), run on an Apple Macintosh Computer, was also used to test the data against a model based upon the function y=A*Sin(x+B)+C. This package generated numerical values for A, B and C, giving a modelled curve fitting the data, then derived a measure of the total variance accounted for by the model and calculated the determination coefficient (r^2) from which the correlation coefficient (r) and an indication of the statistical significance of the model's fit to the data could be calculated.

To investigate the possible role of time of year of conception on later sex ratio, a linear regression relating monthly sex ratio with the mean day length of the putative month of conception - taken nine months before that of delivery (Russell, Douglas and Allan 1993) - was also performed. Mean day length was calculated as the time of sunset minus the time of sunrise - these times being obtained for the Hawarden area using the astronomical software package *Voyager II* (Carina Software Co. CA.), also run on an Apple Macintosh.

Further regression analysis was then performed on the components of sex ratio - the number of males and females born during each month, using the numbers adjusted for month length.

Figure 1
The Old County of Flintshire - N.E.Wales
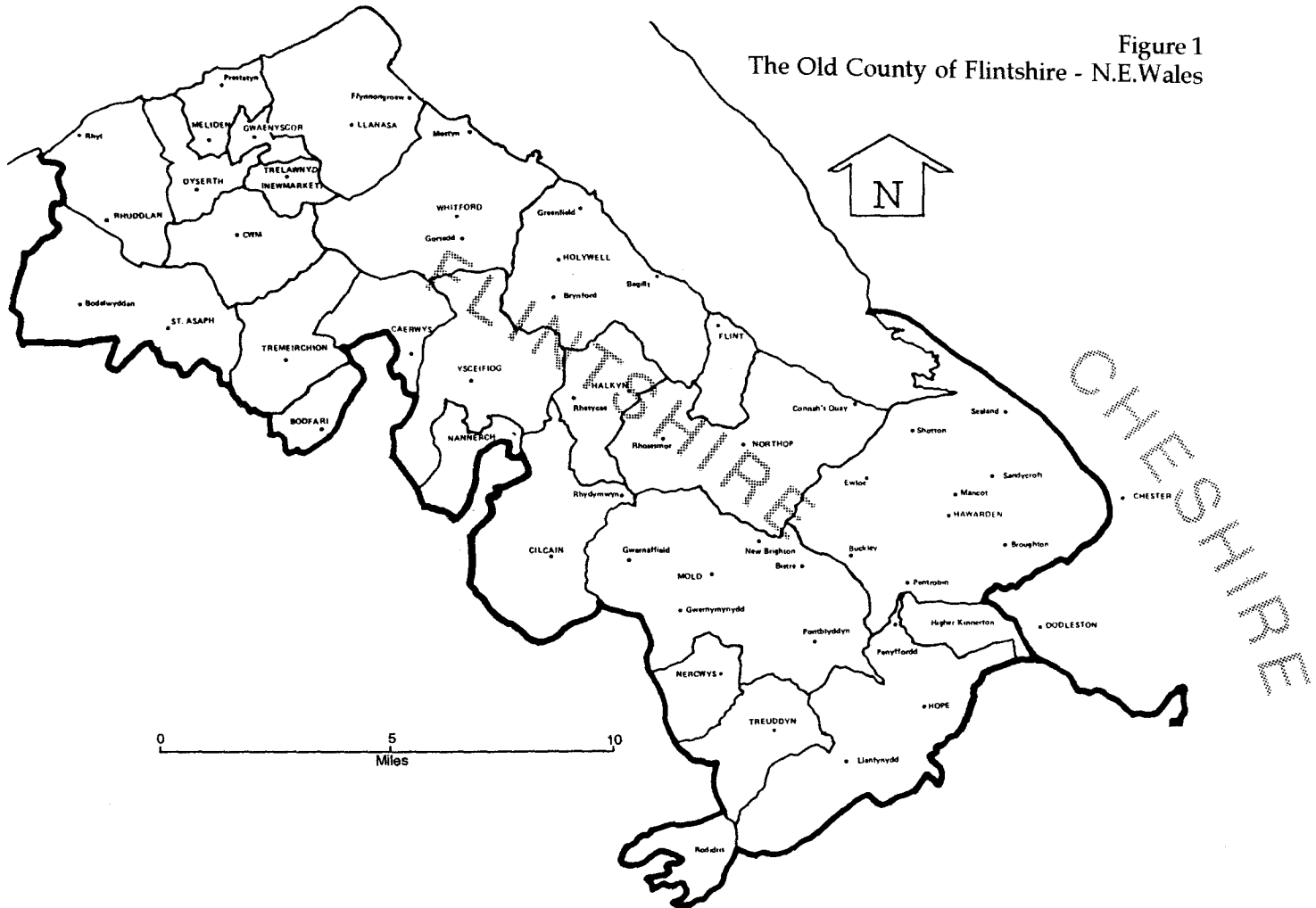
Results

The recorded monthly sex ratio, birth totals and adjusted birth totals for males and females are presented in Table 1. An annual sex ratio of 105.3% was recorded. The monthly deviation from this value is plotted in Figure 2a. This shows a general excess in sex ratio during the summer and autumn and a deficit during winter and spring. Figure 2b presents these findings in terms of the monthly deviation, from their respective annual averages, of the number of males and females born.

The regression analysis produced a modelled curve for sex ratio (Figure 3) with the equation:

$$y = 8.7 \times Sin(x-127.6)° + 105.3$$

The fit to the data was statistically significant with a correlation coefficient of 0.728 (p=0.007), with 53.0% of the total variance accounted for by the model. A peak in modelled sex ratio curve is evident during August and a trough during February - corresponding to conceptions occurring during the previous November and May, respectively.

A statistically significant negative correlation between monthly sex ratio and mean day length of the putative month of conception was observed (r=0.638 (p=0.026)) (Figure 4).

When the data were separated into the (adjusted) number of each sex born per month and further regression analyses performed, both sexes showed modelled peaks occurring at similar times (males: April; females: March) and which were of similar magnitude (Figures 5a and 5b). The equations for each of these curves were:

Males: $y = 22.1 \times Sin(x-9.9)° + 249.5$
Females: $y = 34.3 \times Sin(x+19.6)° + 236.8$

When the modelled curves for male and female birth rates are plotted with sex ratio (Figure 6), the peak in sex ratio appears to be a product of a deeper trough in the number of females born during that part of the year as compared with males. Furthermore, the modelled female cycle appears more marked (as indicated by the larger 'A' factor in the modelled equation) and shows a greater statistical significance than shown by males - indicating a closer fit to the modelled equation (males: r=0.715 (p=0.009); females: r=0.869 (p=0.0002)).

Table 1
Sex Ratio and Births in Hawarden and Northop 1837-1886

	Sex Ratio (%)	Males		Females		Total Born per Month
		Number born per month	Adj for month length	Number born per month	Adj for month length	
January	97.8	263	254.5	269	260.3	532
February	100.0	241	255.9	241	255.9	482
March	101.1	286	276.8	283	273.9	569
April	99.7	290	290.0	291	291.0	581
May	102.0	261	252.6	256	247.7	517
June	115.9	248	248.0	214	214.0	462
July	109.7	272	263.2	248	240.0	520
August	104.0	235	227.4	226	218.7	461
September	124.8	257	257.0	206	206.0	463
October	111.4	244	236.1	219	211.9	463
November	111.5	223	223.0	200	200.0	423
December	94.3	216	209.0	229	221.6	445
	105.3%	3036		2882		5918

Figure 2a   Monthly deviation of sex ratio from the annual average.
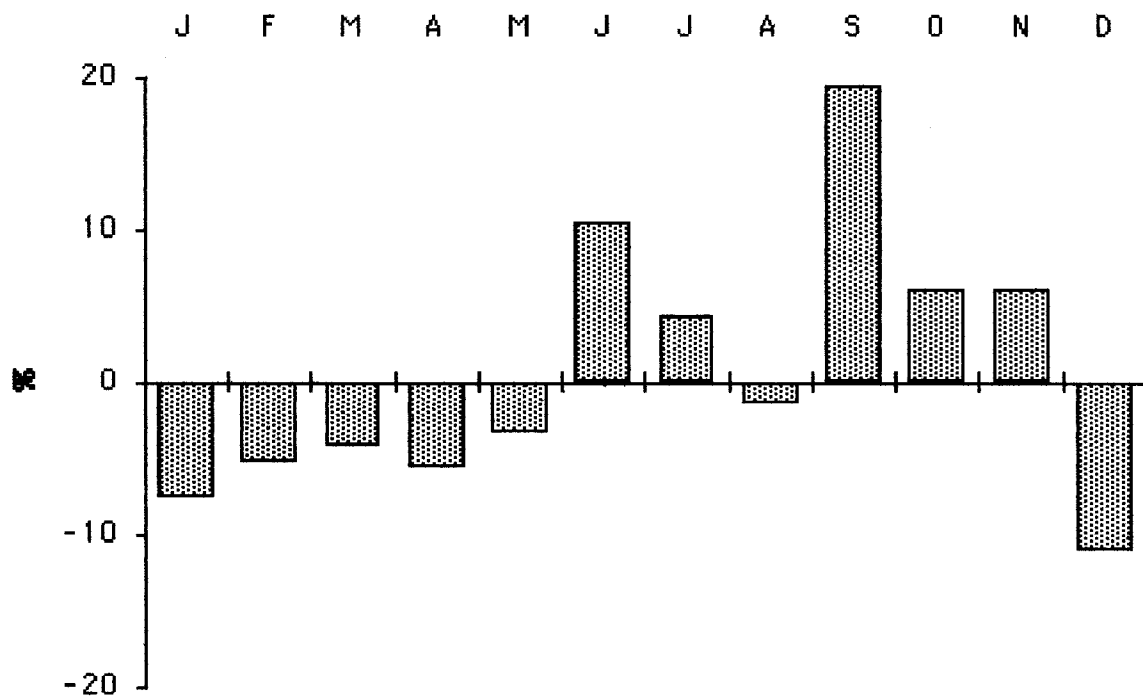(In percentage points)

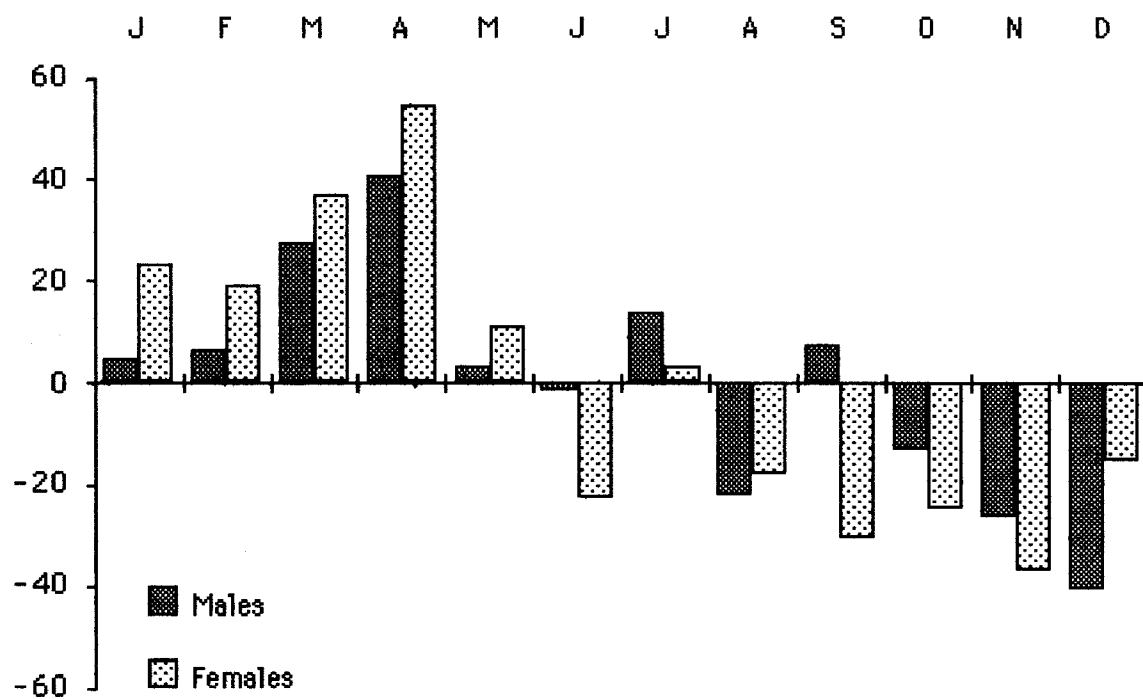**Figure 2b**   Monthly deviation from annual average, of numbers born, by sex.

Figure 3 Seasonal Trends in Secondary Sex Ratio
(Numbers born - open circles, Modelled curve - chained dots)

Modelled Curve: $y = 8.7 \times \mathrm{Sin}(x-127.6)° + 105.3$

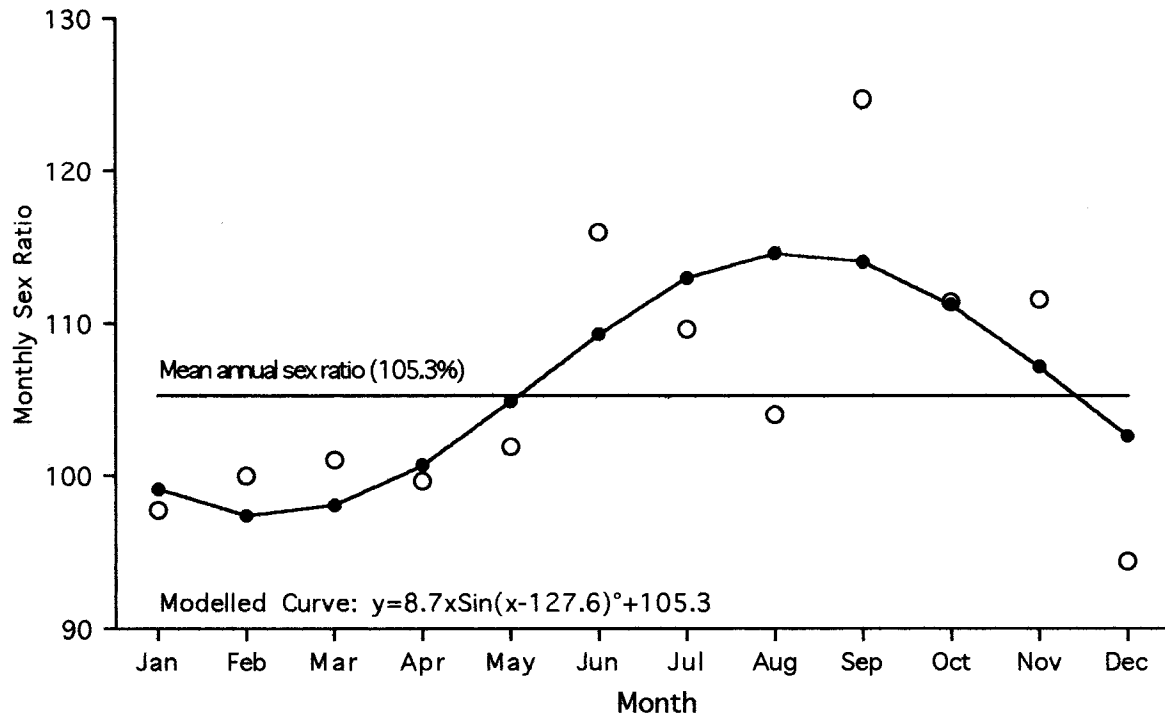Mean annual sex ratio (105.3%)

Figure 4   Secondary sex ratio in relation to the average day length of month of conception.
                (Regression line y = -1.7x + 126.9)
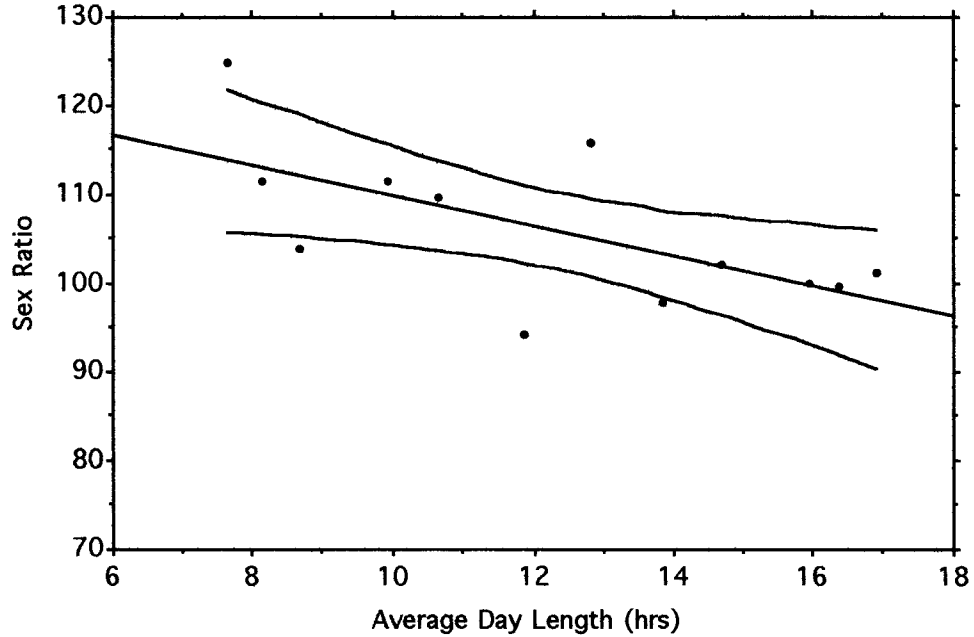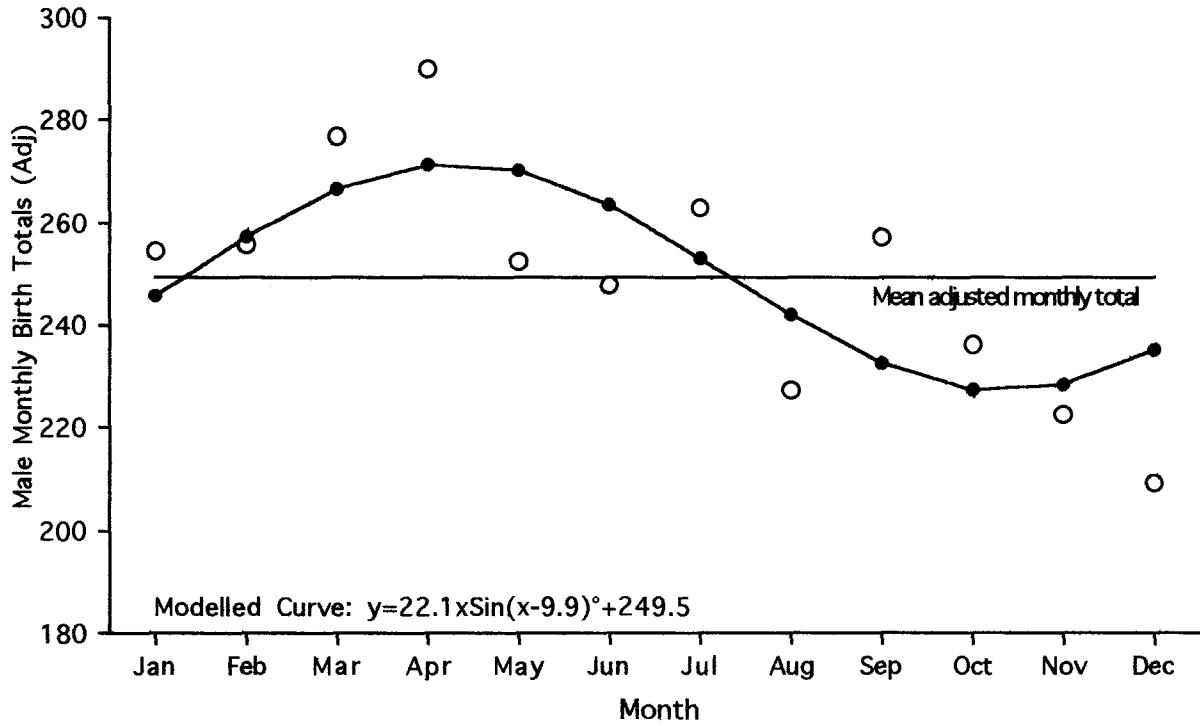
Figure 5   Seasonal Trends in Male and Female Birth Rates

(a) Males   (Numbers born - circles, Modelled curve - chained dots)

Modelled Curve: $y = 22.1 \times Sin(x-9.9)° + 249.5$

(b) Females   (Numbers born - circles, Modelled curve - chained triangles)

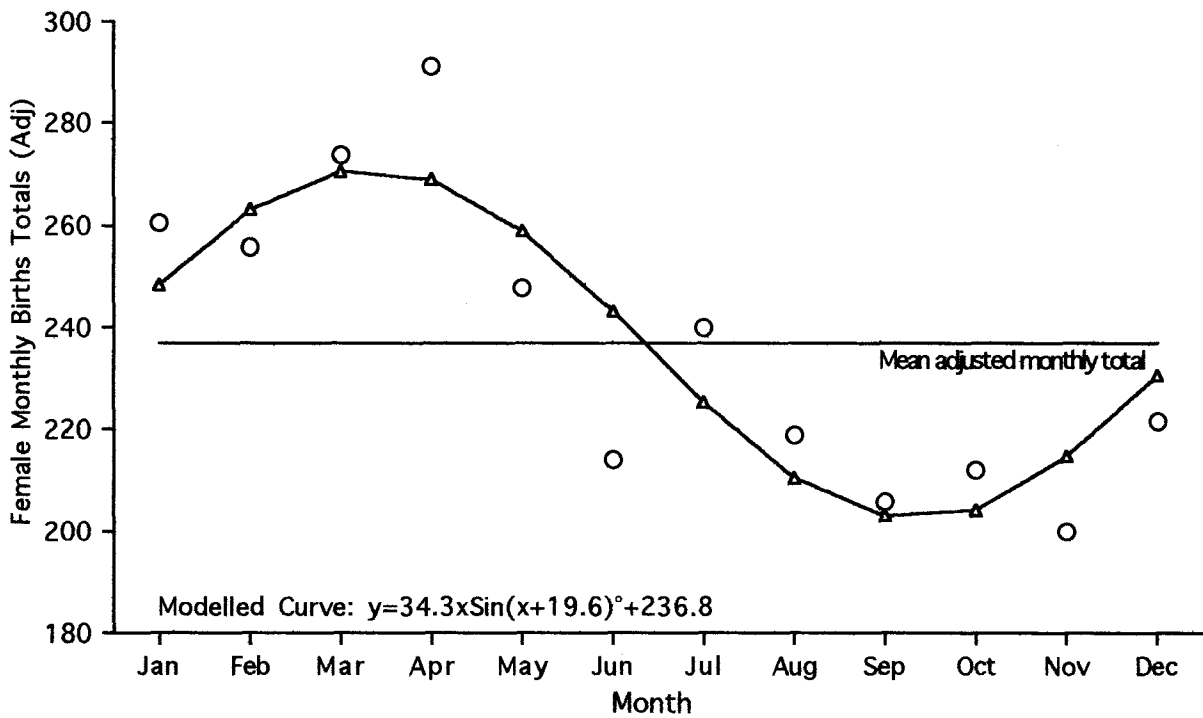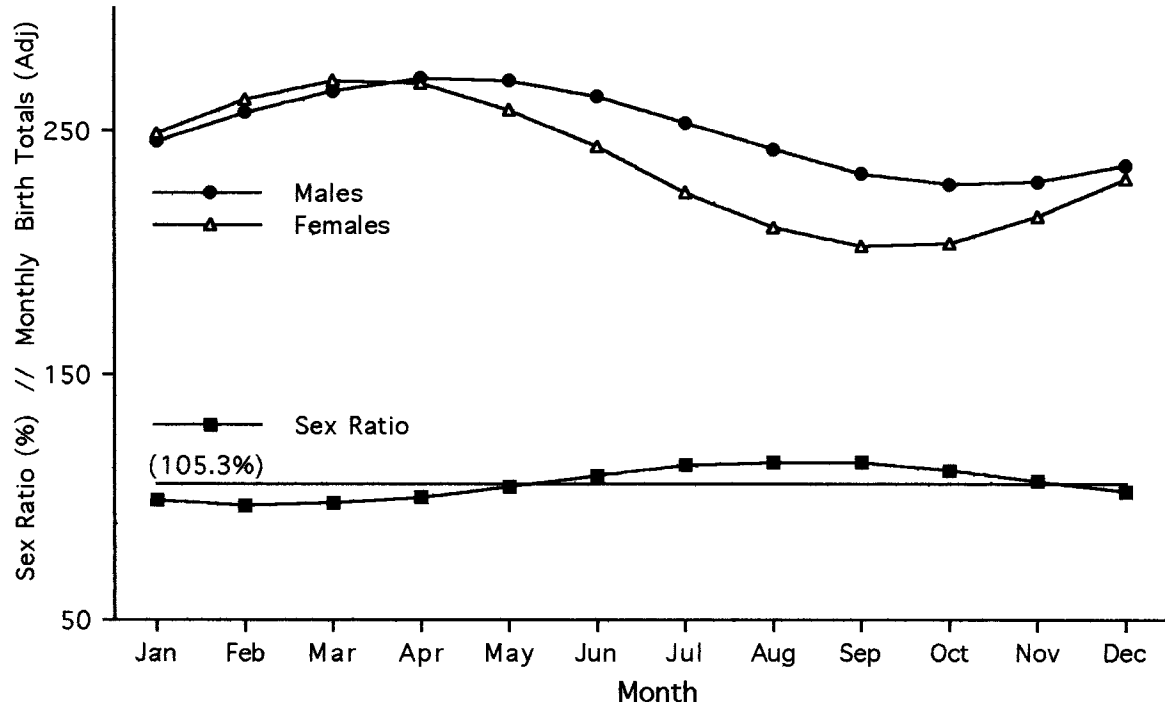Modelled Curve: $y = 34.3 \times Sin(x+19.6)° + 236.8$

Figure 6　　　　A comparison of seasonal trends in sex ratio and male and female monthly birth totals.

Discussion

The present study found a secondary sex ratio of 105.3% in keeping with findings elsewhere (Overfield 1995). The present study was also in general agreement with the findings of Nonaka et al. (1987a) that, in Japan, a sex ratio minimum was evident in March, with a maximum later in the year (November in their case; September here). This is in keeping with the suggestions by Huntington (1938) and Takahashi (1978) that sex ratio is lower in the season when the birth rate (of both sexes combined) exceeds the annual average. However, seasonal trend in male and female births, and how these influence sex ratio, seems to have received little (if any) previous treatment.

The findings in the present study suggest that the way in which the birth rates of the sexes varies circannually may be more informative than a consideration of sex ratio alone - even sex ratio considered circannually. When Walby, Merrett, Dean and Kirke (1981) found an unusually low sex ratio of births in the whole of Ireland for the year 1978, indications were that this was due not to an excess of females but to a deficit of males. In the context of the present study, if such a deficit of males were spread evenly throughout the year, this would result in a downward shift in the cycle for male birth rate and have the effect of deepening the spring trough in sex ratio and reducing the late summer peak. In the present study, it is the late summer peak in sex ratio which seems to account for the bulk of the male excess evident when the data are averaged out.

Factors that influence sex ratio are numerous and include ABO blood groups (Allan 1959, 1972; Plank and Buncher 1975), birth order (Novitski and Kimball 1958), coital rate (James 1971, 1997), contraception (Cruz-Coke 1976), maternal gonadotrophin levels (James 1980), infections (hepatitis - Robertson and Sheard 1973, influenza - Griffiths, Ronalds and Heath 1980, measles - Langaney and Pison 1979), month of mother's birth (Nonaka et al. 1987b), rainfall (Lyster and Bishop 1965), schizophrenia (Lane 1969), smoking (Butler and Alberman 1969), time of insemination (Guerrero 1974; James 1971, 1997) and high performance piloting (military aircraft - Snyder 1961; spacecraft - see Overfield 1995).

So varied and wide ranging is this (incomplete) list of factors that it is difficult to determine any unified, underlying mechanism in action. Indeed, the implication may be that sex ratio is a quite volatile parameter under continual modification but that this has been masked by the time frames used previously for its measurement. This may be due, in part, to sex ratio being a derived parameter which characterizes groups. Natural selection does not work on groups directly. Its actions are effected via the individuals that comprise those groups. In considering the male and female components of sex ratio, one may be closer to the action of natural selection in balancing the sexes.

Conclusion

Although a very useful dimensionless parameter, secondary sex ratio has usually been viewed as an overall, annual population feature rather than a dynamic variable exhibiting seasonality. The findings of the present study suggest that sex ratio is not simply a matter of a numerical excess of males over females born in a given year. Within that period, a more strongly cyclical female birth rate exhibiting a more marked late summer deficit than exhibited by males seems to be an important contributary factor to the overall annual excess in males and so to a sex ratio greater than 100%.

The differential loss in males pre- and postnatally appears to make essential a biological mechanism ensuring that the number of males born exceeds that of females to a consistent extent. However, since sex ratio is a derived parameter, it cannot be acted upon directly by natural selection. Instead, sex ratio must be maintained via selective forces acting upon its individual determinants, in particular, it seems, the way in which male and female birth rates exhibit their own cyclical trends.

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