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Amazon Forest Fires Between 2001 and 2006 and Birth Weight in Porto Velho

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Abstract Intentional forest fires in the Amazon pose a serious environmental problem to the delicate balance of the rain forest and human health. Birth weight data (22,012 live-births) from a public hospital in Porto Velho (Amazon) was used in multiple statistical models to assess the effects of forest-fire smoke on human reproductive outcome. Only when tested for birth weight as a function of months of a determined year there were significant differences for both boys and girls; the significant difference corresponded to months (March and November of 2003) with the highest number of heat spots.

Keywords Forest fires · birth weight · ANOVA · regression model

The aggressive occupation of the Brazilian Amazon dates back to the expansion of the agricultural frontier that started in the 1970s with the opening of roads. Agriculture, mining, and economic development have led to human occupation and emergence of urban centers in the West Amazon; the state of Rondonia bordering Bolivia, is one of the most impacted by forest fires due to its expanding agriculture and mining activities. Government incentives boasted large-scale agriculture projects, always starting with forest clearances by fire (Aragão and Shimabukuro 2010). Agricultural land claimed from the felled forest has been made into cropland and pasture, which is managed by fire. Despite official efforts to limit further forest land occupation or preservation, the increasing price of meat (green meat) and soy beans has driven forest destruction at alarming rates in the last 10 years (Aragão and Shimabukuro 2010); all done by using deliberate but out of control forest fires. The extent of the felled native forest and, the continuing ecological damage to the native flora and fauna remain unknown. However, there have been attempts to assess health impacts on some urban centers.

Ignotti et al. (2010) showed an association of atmospheric pollution (due to forest burning) with occurrences of respiratory diseases (in children and the elderly) in the Brazilian Amazon region.

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Respiratory diseases in the elderly due to forest fires accounted for 50 to 80% of mortality rate in the state of Rondonia between the years of 1998 and 2005 (Castro et al. 2009). Also in the West Amazon, Mascarenhas et al. (2008) measured particulate matter < 2.5microm (resulting from forest fire) and showed its association with increased rates of respiratory diseases in children < 10 years of age.

This study is a first attempt to assess the impact of atmospheric pollution brought about Amazon forest fires on reproductive outcomes (birth weight) in a large urban center - the city of Porto Velho - located in the most impacted region of deforestation and human occupation in the Amazon.

Materials and Methods

This is part of our ongoing project on environmental hazards to children's health in the West Amazon (Dórea et al. 2007); the research protocol was approved by the Ethics Committee of Studies for Humans of the Universidade Federal de Rondonia. We had access to the birth records of children born at the Hospital de Base, the largest public hospital facility caring mostly for the lower middle class in the city of Porto Velho (capital of the state of Rondonia, West Amazonia). A parent publication dealing with ethylmercury exposure derived from Thimerosal-containing vaccines given to newborns appeared elsewhere (Dórea et al. 2009).

We collected data of live births occurring from 2001 to 2006; these data were recorded by hospital staff and comprised live birth-weight, sex, and date of birth. The total number of observations for the period was $n = 22012$ with a sex proportion of 48.4% of females and 51.6% males. Forest fire information was based on data collected by the satellite NOAA-12 with records summarized monthly.

Figure 1 shows the observed values of the birth weights for girls (left plot) and for boys (right plot), during the studied period. The lack of observations during the period from 12/02/2002 to 02/03/2002 corresponds to interrupted services at the maternity ward due to building repairs on the hospital.

The descriptive statistics for the birth weight data are presented in Table 1. The range of variation is wider for girls (4715g) than for boys (4570g); moreover, both, minimum and maximum weights are higher for girls than for boys (see Table 1). Nevertheless, the coefficient of variation (CV) is relatively low for both girls and boys.

Table 1 Descriptive statistics of the birth weight by sex in the period of 2001-2005.

Sex	Min	1st Q	Median	Mean	3rd Q	Max	DP	CV
F	1185	2900	3200	3193	3490	5900	450.837	0.141
M	1160	3000	3305	3310	3600	5730	477.659	0.144

The data are also illustrated in Figures 2(a) and 2(b) as a histogram and a box-plot, respectively. While the histogram shows an overall symmetry between girls and boys regarding ranges of birth weight, the box-plot indicates the presence of outliers in the data. The frequency of outliers for boys is 1.66% and, for girls is 1.02%.

Table 2 shows a summary of heat spots captured by satellite images for the state of Rondonia during the studied period; the total number of heat spots varied on a yearly basis, almost doubling from 2001 to 2002 then decreasing from 2002 to 2003, rising again from 2003 to 2004 and from 2004 to 2005. Altogether, the number of heat spots practically doubled from 2003 to 2005. An illustration of heat spots is graphically shown in Figure 3; it is worth noting that their occurrence is higher during the second semester, which is the dry season (see Figure 3 and Table 2). In tandem with this observation, if forest fires affected birth weights more light children would be expected during the first semester than in the second semester. Furthermore, for years with a higher number of heat spots one would also expect more light birth weights.

Table 2 Number of heat spots captured by satellite images for the state of Rondonia during the studied period.

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
2000	0	6	9	0	0	54	116	2196	2437	643	12	6	5485
2001	0	2	0	0	5	31	74	2133	1927	796	91	1	5060
2002	6	8	1	3	10	141	285	1872	6095	1874	146	20	10461
2003	8	2	1	0	34	66	668	4126	2742	1286	134	63	9130
2004	4	4	3	2	7	126	558	3718	6937	1725	99	17	13200
2005	7	0	0	2	12	82	580	6699	8775	1502	158	1	17818
Total	25	22	14	7	68	500	2281	20744	28913	7826	640	108	61154

Source: INPE - Satellite NOAA-12

It can be noticed that the greatest number of fires occurred during the months of August and September of any given year, which correspond to the peak of the dry season. Considering that the last semester of pregnancy could be the most determinant of birth weight, it is expected that March to June should show effect. We speculate that the smoke pollution from forest fires can be unfavorable for the first months of a pregnancy because they could affect the fetus initial development, thus modulating weight gain throughout pregnancy. Besides, a quite well developing fetus has more metabolic chances of gaining weight than one with an initial developmental hindrance.

In order to identify a possible relation between the numbers of heat spots that occurred during pregnancy and related birth weight we considered a multi-step approach. First we used ANOVA (Scheffé 1959) to identify whether the sex or the semester, the month or the year of birth, had any influence on the birth weight. After that we considered a regression model that took into account the information obtained in the first step to explain the mean birth weights as a function of the number of heat spots.

Results and Discussion

As a result of the apparent differences shown in Table 1, a preliminary analysis to assess the influence of sex was necessary in order to establish if further analysis would have to consider this variable in the statistical model. We tested this hypothesis and, indeed, there was a statistically significant difference between the means ($F = 349.19$ with p-value $<2.2e\text{-}16$ at a confidence level of 99.9%). Due to sex effects on birth weight, we included it in the analysis to assess the influence of the heat spots on birth weight. Due to the variation in number of heat spots over the years, several ANOVA tests were performed in order to identify the time (year) effect on birth weight; each sex was analyzed independently.

When considering year as the only variable we cannot reject the null hypothesis that annual means are equal in both cases (girls: $F = 0.4854$, p-value $= 0.7465$; boys: $F = 1.0118$, p-value $= 0.3997$). Because heat spots occur during the dry season, the time effect was also analyzed as a function of semesters only. In this case also no statistically significant differences between the means for the first and second semesters were found (girls: $F = 1.814$, p-value $= 0.1781$; boys: $F = 2.3279$, p-value $= 0.1271$).

Figure 4(a) shows mean birth weight per semester for each studied year. One observes that only in 2003 there is a noticeable increase in birth weight for the second semester for both sexes. Figure 4(b) shows the mean birth weight by year for each fixed semester. It is worth noting that for the boys there was a noticeable decrease in birth weight in the first semester of 2002 that might be a bias introduced due to lower number of observations.

The analysis done independently for semesters and for years showed no statistically significant difference; therefore, we decided to test the combined effects of year and semester in a single statistical model. In this test we hoped to scrutinize for relationship of birth weights and number of heat spots occurring in a specific period of a specific year. In that way if there was a mean birth weight of a semester that would differ from another, it could possibly be detected.

For girls, when we consider the semester by year there was no statistically significant effect (F = 0.8683, p-value = 0.553); also when we analyze a fixed semester and compare the mean for different years, there was also no statistically significant difference (F = 1.0743, p-value = 0.3674) for the first and second semesters (F = 0.4282, p-value = 0.7884). However, for boys, using a similar model, there was a statistically significant effect (F = 2.7001, p-value = 0.0039). As shown in Figure 4(a), the mean differing from the others is the one from the first semester of 2002. Because of the confounding of fewer observations in that specific semester (first semester of 2002) these results are considered an analytical artifact. By comparing the means for different years in a fixed semester, we can reject the null hypothesis that they are equal (F = 2.7583 with p-value = 0.0263 and for the second semester, F = 2.72554 with p-value = 0.0278); Figure 4(b) clearly shows an anomaly in the first semester of 2002, and in the second semester of 2003. Although we realize that the low mean weight observed during the first semester is unlikely to be related to forest fires the mean birth weight observed in the second semester of 2003 could possibly be related to the high number of heat spots (34) registered in the first semester of 2003.

Figures 5 and 6 illustrate mean birth weight per month by year; the effects of months throughout the studied years showed a significant effect for both sexes (girls: F = 1.2440, p-value = 0.0989; boys: F = 1.5104, p-value = 0.0079). Figure 5 shows that for both girls and boys, the salient mean birth weight corresponds to March-2002. Considering months as a fixed effect over the years there was no significant difference between the means, except for March, in the case of girls (F = 5.9700, p-value = 9.938e-05) and of boys in March (F = 2.648, p-value = 0.0323) and November (F = 4.8289, p-value = 0.0007). It should be noted that the semester mean (as a function of year) showed significant differences; indeed, from Figure 6, one observes that for March, this was the case with both boys and girls. From Table 2 it can be seen that March-2003 showed the highest number of heat spots, compared to March from other years.

Mean birth weight was statistically different between boys and girls; therefore we used a model for each sex to explain mean birth weight, not individual birth weight. The models used for girls and boys accounted for month, semester, and year of birth as well as number of heat spots. For the variable 'number of heat spots' we considered number of cases corresponding to a gestation period and overall number for a specified gestation period. After a careful step-by-step run of several statistical models we could conclude that:

- **Girls:**
  a) Mean birth weight for girls does not depend on month, semester, or year when these variables are analyzed separately.
  b) When mean birth weight is analyzed as a function of a specific month and year, a significant difference is detected for March-2002. However, further detailed analysis showed that introducing a constant for March and April of 2002 explains variations in birth weight for girls. As a consequence there was no statistically significant evidence that birth weight for girls can be affected by number of forest fires.
- **Boys:**
  a) Overall, when the variables month, semester, and year are considered per se, there is no statistically significant difference. However, further detailed analysis showed a significant factor influencing mean birth weight for the period from March to June of 2002.
  b) In order to introduce the 'number of heat spots' variable in the model, we included it as a new variable, denoted by $N(\cdot)$, and tested the following possibilities:
     - $N(\cdot)$ = Number of heat spots in i-th month of gestation, where $i \in \{0, 1, \cdots, 9\}$,
     - $N(\cdot)$ = Sum of the number of heat spots from month i to j, with $i \leq j$ and $i, j \in \{0, 1, \cdots, 9\}$,

     where, by definition, "0" is the month at which pregnancy has started.

Among all tested models, the best to explain mean birth weight variation (considering the value of the statistic R^2 in the regression model) were:

- **For girls:** $W(m) = \mu + a\,\mathbb{I}_A(m) = 3196.454 - 340.404\,\mathbb{I}_A(m)$, where m is the birth period, $A = \{\text{March} - 2002, \text{April} - 2002\}$ and $\mathbb{I}_A(\cdot)$ is the indicator function of set A, which is defined by $\mathbb{I}_A(m) = 1$, if $m \in A$, and $\mathbb{I}_A(m) = 0$, if $m \notin A$. The coefficients of the model, its p-value, and the R^2 value are shown in Table 3. The value of R^2 indicates that 65% of the variation of the mean birth weight for girls can be explained by this model. Figure 7(a) illustrates the girls' monthly mean birth weight (in red) and respective values estimated by the model (in black) for the period of 2002 to 2005.

– **For boys:** $W(m) = \mu + a\,\mathbb{I}_A(m) + bN(m) = 3321 - 168.8\,\mathbb{I}_A(m) - 0.004485N(m)$, where m is the birth period, $A = \{\text{March} - 2002, \text{April} - 2002, \text{May} - 2002, \text{June} - 2002\}$, $\mathbb{I}_A(\cdot)$ is the indicator function of set A, and the N variable is defined as $N(m) = \sum_{j=0}^{1} n_j$, where n_j is the number of heat spots after the j-th month of gestation and n_0 is the gestation initial month. The coefficients of the model, its p-value, and the R^2 value are shown in Table 4. The value of R^2 indicates that 54% of the variation of the mean birth weight for boys can be explained by this model. Figure 7(b) illustrates the boys' monthly mean birth weight (in red) and respective values estimated by the model (in black) for the period of 2002 to 2005. The model captured the most accentuated decreases of mean birth weight (see Figure 7(b)) however it failed to capture the birth weight fall of November-2003.

Table 3 Final model for Girls mean birth weight

Coeff.	Estimate	Std. Error	t value	Pr(> |t|)
μ	3196.454	5.896	542.13	< 2e-16 ***
a	-340.404	32.294	-10.54	4.25e-15 ***

Residual standard error: 44.9 on 58 degrees of freedom (df)
Multiple R-squared: 0.657; Adjusted R-squared: 0.6511
F-statistic: 111.1 on 1 and 58 df, p-value = 4.254e-15

Significance code: 0 '***'

Table 4 Final model for Boys mean birth weight

Coeff.	Estimate	Std. Error	t value	Pr(> |t|)
μ	3.321e+03	6.356e+00	522.566	< 2e-16 ***
a	-1.688e+02	2.178e+01	-7.749	1.79e-10 ***
b	-4.485e-03	2.168e-03	-2.069	0.0431 *

Residual standard error: 41.9 on 57 degrees of freedom (df)
Multiple R-squared: 0.5429; Adjusted R-squared: 0.5269
F-statistic: 33.85 on 2 and 57 df, p-value = 2.044e-10

Significance codes: 0 '***' 0.001 '**' 0.01 '*'

The smoke and particulate matter generated by forest fires currently going on in the Amazon have been positively associated with morbidity and mortality of vulnerable groups (Mascarenhas et al. 2008; Castro et al. 2009; Ignotti et al. 2010). These effects are caused by impairment of lung function due to physicochemical properties of the inhaled particles (Schwarze et al. 2006). Population based studies have shown an increased risk of low birth weight associated with households that use biomass fuel (Boy et al. 2002; Siddiqui et al. 2008; Tielsch et al. 2009; Thompson et al. 2011). In these studies exposure to biomass fuel smoke is chronic (on a daily basis) while forest fires are seasonal. In the former case confounding variables (like cigarette smoke) are simpler to factor out (Sreeramareddy et al. 2011; Abusalah et al. 2011). In ecological studies like the present one, confounding/intervening variables were impossible to adjust in a single statistical model.

We noticed that, all analysis indicating that the means are not statistically equal, also indicated that differences occurred in the means corresponding to the period with missing observations. Dealing with missing data is always challenging and, based on these findings, we believe that a more complete data set could lead to different models and attendant outcomes. For instance, the indicator function, included in both models to account for the information that is not available, would not be necessary.

We could not control for variables (constitutional or environmental) known to interact with reproductive outcomes related to birth weight. On a population based birth weight outcome there was no direct association of a particular year or season. However, our study showed air pollution (derived from forest fires) to have an unfavorable association with birth outcomes.

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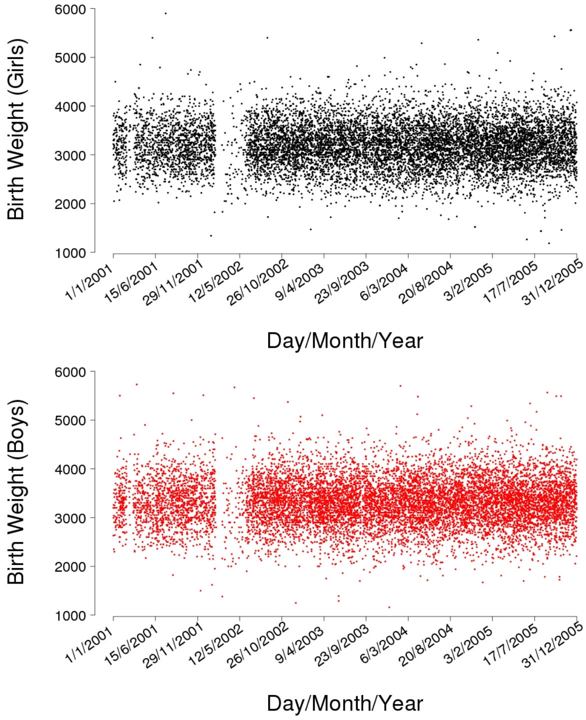
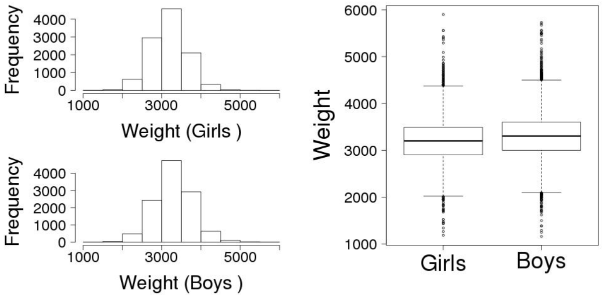
Figure 1.



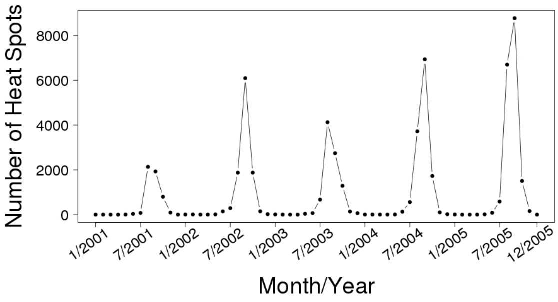
Birth Weight (Girls)
6000
5000
4000
3000
2000
1000
1/1/2001
15/6/2001
29/11/2001
12/5/2002
26/10/2002
9/4/2003
23/9/2003
6/3/2004
20/8/2004
3/2/2005
17/7/2005
31/12/2005
Day/Month/Year
Birth Weight (Boys)
6000
5000
4000
3000
2000
1000
1/1/2001
15/6/2001
29/11/2001
12/5/2002
26/10/2002
9/4/2003
23/9/2003
6/3/2004
20/8/2004
3/2/2005
17/7/2005
31/12/2005
Day/Month/Year

Figure 2.


Frequency
4000
3000
2000
1000
0
1000
3000
5000
Weight (Girls)
Frequency
4000
3000
2000
1000
0
1000
3000
5000
Weight (Boys)
6000
5000
4000
3000
2000
1000
Weight
Girls
Boys

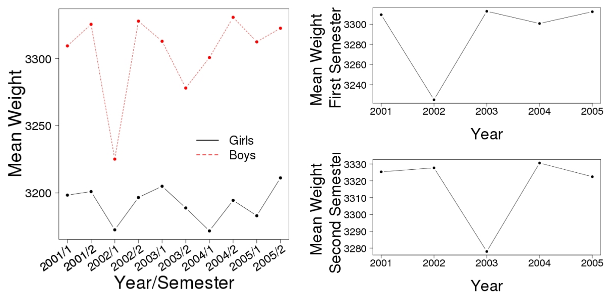
(a) (b)

Figure 3.



Number of Heat Spots
8000
6000
4000
2000
0
1/2001
7/2001
1/2002
7/2002
1/2003
7/2003
1/2004
7/2004
1/2005
7/2005
12/2005
Month/Year

Figure 4.


Mean Weight
3300
3250
3200
Girls
Boys
2001/1
2001/2
2002/1
2002/2
2003/1
2003/2
2004/1
2004/2
2005/1
2005/2
Year/Semester
Mean Weight
First Semester
3300
3280
3260
3240
2001
2002
2003
2004
2005
Year
Mean Weight
Second Semester
3330
3320
3310
3300
3290
3280
2001
2002
2003
2004
2005
Year

(a) (b)

Figure 5.

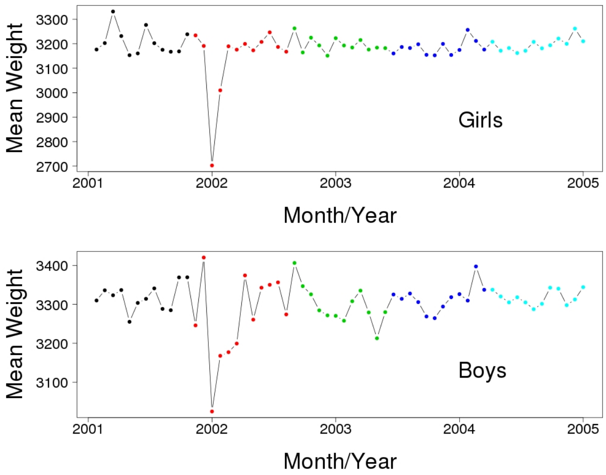
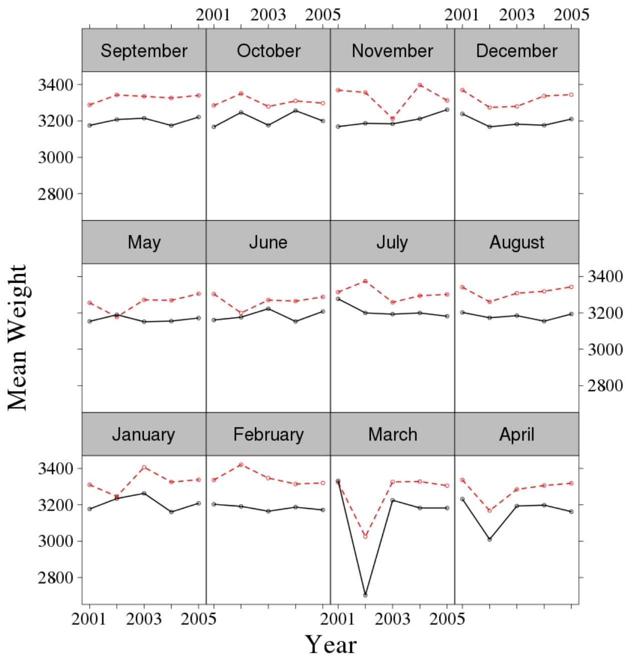
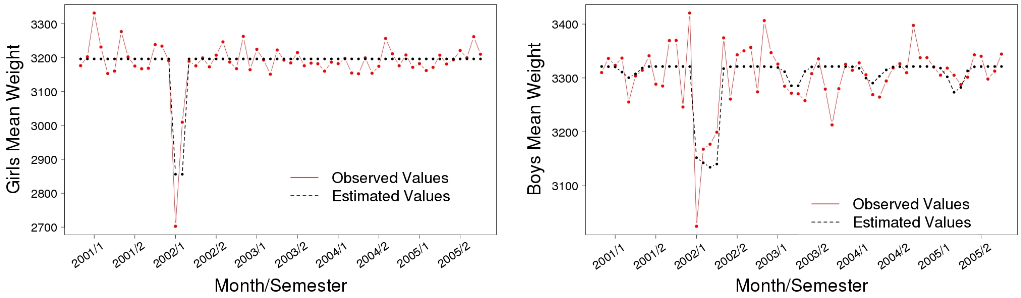

Mean Weight
3300
3200
3100
3000
2900
2800
2700
Girls
2001
2002
2003
2004
2005
Month/Year
Mean Weight
3400
3300
3200
3100
Boys
2001
2002
2003
2004
2005
Month/Year

Figure 6.



September
October
November
December
May
June
July
August
January
February
March
April
3400
3200
3000
2800
2001
2003
2005
Mean Weight
Year

Figure 7.



Girls Mean Weight
3300
3200
3100
3000
2900
2800
2700
Observed Values
Estimated Values
2001/1
2001/2
2002/1
2002/2
2003/1
2003/2
2004/1
2004/2
2005/1
2005/2
Month/Semester
Boys Mean Weight
3400
3300
3200
3100
Observed Values
Estimated Values
2001/1
2001/2
2002/1
2002/2
2003/1
2003/2
2004/1
2004/2
2005/1
2005/2
Month/Semester

Fig. 1 Birth weight for girls and boys, in the period from January 2001 to December 2005.

Fig. 2 (a) Histogram; (b) Box-plot of the weights by sex.

Fig. 3 Number of heat spots by month in the period of January 2000 to December 2005, in Rondonia.

Fig. 4 (a) Mean weight by semester for boys (dashed line) and girls (solid line); (b) Mean weight by semester for boys: First semester (upper plot) and second semester (lower plot).

Fig. 5 Mean weight by month and year: Girls (upper); Boys (lower).

Fig. 6 Mean weight by month for each year for boys (dashed line, in red) and girls.

Fig. 7 Observed monthly mean birth weight for girls and boys and estimated values (dashed line).