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Hurricane Katrina: Influence on the Male-to-Female Birth Ratio

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Key Words
Birth rate · Cyclonic storms · Sex ratio · Disasters · Florida · Alabama · Louisiana · Mississippi

Abstract
Objective: This study was carried out in order to ascertain whether or not Hurricane Katrina and related factors (i.e. the amount of rainfall) influenced the male-to-female birth ratio (M/F). ***Materials and Methods:*** Monthly births by gender for the affected states (Alabama, Florida, Louisiana and Mississippi) for January 2003 to December 2012 were obtained from the Centers for Disease Control and Prevention (CDC Wonder, Atlanta, Ga., USA). Precipitation data was obtained from the US National Weather Service. Ordinary linear logistic regression was used for trend analysis. A p value ≤0.05 was taken to represent a statistically significant result. ***Results:*** Of the total of 3,903,660 live births, 1,996,966 (51.16%) were male and 1,906,694 (48.84%) were female. Significant seasonal variation was noted (the maximum M/F in May was 1.055, the minimum M/F in September was 1.041, p = 0.0073). There was also a separate and significant rise in M/F 8–10 months after the storm (April to June 2006, peak M/F 1.078, p = 0.0074), which translated to an approximate deficit of 800 girls compared to 46,072 girls born in that period if the M/F increase was theoretically only due to a girls' deficit in the numerator of the ratio. This spike was only present in Alabama, Louisiana and Mississippi, all of which received heavy rainfall. Florida did not receive heavy rainfall and experienced no such M/F spike. ***Conclusion:*** In this study there was a dose-response relation between the amount of rainfall after Hurricane Katrina and the monthly sex ratio of live births in the US states of Alabama, Louisiana and Mississippi 8–10 months later. The well-known yet unexplained distinct sex ratio seasonality may be due to natural or man-made radiation contained in the rain.

Introduction

In humans, live male births exceed live female births by approximately 4–6% [1]. This ratio is conventionally expressed as M/F, the sex ratio, or sex odds. A multitude of factors have been implicated as influencing this ratio and most appear to reduce it by inducing spontaneous termination of pregnancy, which affects more male than female foetuses [1, 2]. Other factors include natural disasters such as floods [3] and earthquakes [4], as well as events precipitated by man, including short wars [5], the Great London Smog [3] and terrorist events [6].

Hurricane Katrina formed over the Bahamas in August 2005 and wrought havoc over the southern USA. The storm traversed Florida as a category 1 hurricane (≤74

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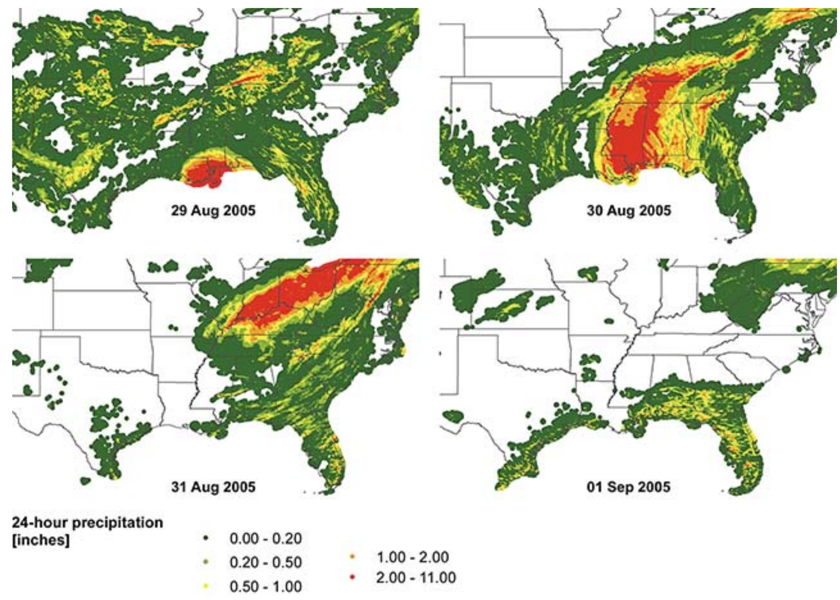

Fig. 1. Precipitation maps of the USA (grey shading) from August 29 to September 1, 2005 (source: US National Weather Service, see table 2) (colour online version only).

mph). It then strengthened over the Gulf of Mexico and struck southeast Louisiana as a category 3 event (≤111 mph) as well as Mississippi, waning away over Alabama [7, 8].

The associated storm surge caused widespread destruction along the Gulf coast and severe floods in New Orleans, which lingered for several weeks. The surge protection failures were classified as the worst civil engineering disaster in the history of the USA [7, 8].

It is known that calamitous events promote spontaneous abortions in stressed, pregnant women [6]. This was evidenced in the USA after the attacks of September 11, 2001. Such losses are male-biased, skewing the sex ratio at birth toward female babies [9]. After Hurricane Katrina, a foetal loss phenomenon was noted (gender unspecified), and this was even related in degree to the extent of property damage [10].

It is also known that M/F is subject to seasonality [11], and that there is a positive association with rainfall levels 9–11 months before birth [12]. Hurricane Katrina was accompanied by heavy rainfall. It brought more rain to Alabama, Louisiana and Mississippi than to Florida because the storm only passed over the northwest tip of Florida [7, 8].

This study was carried out in order to ascertain whether or not this natural event influenced M/F in Alabama, Florida, Louisiana and Mississippi. It was also attempted to determine whether or not the disparate rainfall in these states had a differential effect on M/F.

Subjects and Methods

Monthly male and female live births by state for Alabama, Florida, Louisiana and Mississippi in the USA were obtained from the website of the Centers for Disease Control and Prevention (CDC), as shown in table 1 [13]. The time period analysed was January 2003 to December 2012.

Precipitation data for Alabama, Florida, Louisiana and Mississippi were obtained from the US National Weather Service (table 2) [14]. Precipitation maps of the USA from August 29 to September 1, 2005, are presented in figure 1. Ordinary linear logistic regression was used in order to assess time trends in the occurrence of male live births and to investigate whether there were changes in the trend functions after distinct events. This involved considering the male proportion among all male (m) and female (f) births: $p_m = m/(m + f)$. Important and useful parameters in this context are the sex odds, $SO = p_m/(1 - p_m) = m/f$, and the sex odds ratio (SOR), which is the ratio of two sex odds of interest, i.e. in exposed versus non-exposed populations. Dummy coding was used for single points in time and for time periods. For example, the dummy variable for the time window from 2006 onwards was defined as $d_{2006}(t) = 0$ for $t < 2006$, and $d_{2006}(t) = 1$ for $t \geq 2006$. The SOR peak is defined as the expected sex odds in the time interval from April to June 2006 (4–6/2006) divided by the expected baseline sex odds in that same time interval. The simple and parsimonious lo-

Table 1. Monthly live births for Alabama, Florida, Louisiana and Mississippi, 2003–2012

Date		Alabama		Florida		Louisiana		Mississippi	
year	month	female	male	female	male	female	male	female	male
2003	Jan	2,318	2,548	8,546	8,970	2,626	2,781	1,685	1,834
	Feb	2,150	2,287	7,806	8,322	2,364	2,486	1,535	1,607
	Mar	2,390	2,467	8,238	8,815	2,467	2,508	1,649	1,757
	Apr	2,241	2,465	8,123	8,594	2,490	2,609	1,616	1,608
	May	2,321	2,517	8,410	8,936	2,596	2,640	1,584	1,717
	Jun	2,330	2,473	8,097	8,557	2,455	2,617	1,743	1,762
	Jul	2,600	2,692	8,648	9,251	2,756	2,991	1,760	1,939
	Aug	2,580	2,635	9,167	9,507	2,883	2,969	1,867	1,954
	Sep	2,669	2,652	9,272	9,965	2,961	2,970	1,856	1,859
	Oct	2,572	2,639	9,347	9,842	2,774	2,955	1,883	1,930
	Nov	2,327	2,400	8,507	8,695	2,541	2,754	1,698	1,719
	Dec	2,558	2,721	9,105	9,530	2,874	2,973	1,832	1,986
2004	Jan	2,326	2,490	8,621	9,186	2,763	2,714	1,672	1,736
	Feb	2,188	2,289	8,174	8,446	2,381	2,450	1,626	1,591
	Mar	2,336	2,571	8,682	8,964	2,642	2,739	1,751	1,834
	Apr	2,311	2,358	8,496	8,869	2,477	2,673	1,679	1,724
	May	2,340	2,431	8,292	8,878	2,377	2,536	1,639	1,688
	Jun	2,386	2,552	8,640	9,065	2,667	2,785	1,737	1,780
	Jul	2,461	2,671	9,112	9,488	2,721	2,910	1,810	1,863
	Aug	2,491	2,640	9,136	9,731	2,730	2923	1,813	1,923
	Sep	2,526	2,717	9,578	9,968	2,859	3,039	1,930	1,902
	Oct	2,421	2,640	9,187	9,724	2,813	2,888	1,755	1,897
	Nov	2,490	2,617	8,857	9,531	2,716	2,820	1,768	1,914
	Dec	2,605	2,653	9,525	9,903	2,808	2,938	1,791	2,004
2005	Jan	2,386	2,570	9,160	9,317	2,578	2,783	1,743	1,792
	Feb	2,175	2,303	8,278	8,710	2,386	2,480	1,506	1,634
	Mar	2,447	2,506	9,019	9,500	2,618	2,767	1,629	1,846
	Apr	2,331	2,346	8,517	8,756	2,424	2,468	1,570	1,670
	May	2,429	2,476	8,698	9,232	2,553	2,647	1,648	1,826
	Jun	2,533	2,644	8,987	9,425	2,582	2,817	1,794	1,745
	Jul	2,499	2,609	9,224	9,743	2,548	2,561	1,766	1,794
	Aug	2,613	2,808	9,949	10,433	2,551	2,691	1,862	1,895
	Sep	2,636	2,715	10,189	10,454	2,523	2,663	1,851	1,911
	Oct	2,443	2,600	9,416	9,928	2,357	2,409	1,760	1,851
	Nov	2,578	2,550	9,717	9,872	2,314	2,366	1,745	1,778
	Dec	2,543	2,713	9,574	10,142	2,346	2,505	1,848	1,931
2006	Jan	2,510	2,566	9,416	9,830	2,367	2,569	1,795	1,880
	Feb	2,325	2,471	8,908	9,004	2,211	2,231	1,682	1,718
	Mar	2,544	2,694	9,496	10,015	2,448	2,591	1,779	1,847
	Apr	2,286	2,479	8,547	9,028	2,166	2,290	1,620	1,763
	May	2,420	2,652	9,103	9,683	2,275	2,546	1,701	1,930
	Jun	2,434	2,658	9,282	9,743	2,463	2,665	1,775	1,941
	Jul	2,670	2,706	9,725	9,995	2,670	2,826	1,806	2,028
	Aug	2,836	3,044	10,544	11,067	2,932	3,193	2,140	2,212
	Sep	2,694	2,809	10,530	10,839	2,905	2,973	2,090	2,184
	Oct	2,666	2,846	10,298	10,672	2,834	2,935	2,050	2,056
	Nov	2,613	2,852	9,788	10,401	2,754	2,910	1,944	2,066
	Dec	2,611	2,846	10,180	10,708	2,783	2,839	1,984	2,065

Table 1 (continued)

Date		Alabama		Florida		Louisiana		Mississippi	
year	month	female	male	female	male	female	male	female	male
2007	Jan	2,622	2,693	9,850	10,554	2,756	2,876	1,916	2,076
	Feb	2,496	2,440	8,977	9,560	2,454	2,554	1,763	1,799
	Mar	2,621	2,722	9,649	10,135	2,652	2,747	1,924	1,994
	Apr	2,462	2,646	9,053	9,387	2,439	2,518	1,680	1,754
	May	2,633	2,691	9,578	10,031	2,560	2,668	1,802	1,902
	Jun	2,450	2,609	9,299	9,940	2,651	2,650	1,821	1,935
	Jul	2,801	2,879	9,902	10,581	2,778	2,929	1,896	2,068
	Aug	2,985	2,927	10,680	11,127	2,975	3,172	2,061	2,167
	Sep	2,708	2,850	9,777	10,134	2,831	2,894	1,927	2,006
	Oct	2,771	2,859	9,949	10,575	2,834	2,978	1,974	2,069
	Nov	2,700	2,843	10,047	10,257	2,867	2,836	1,888	2,026
	Dec	2,693	2,703	9,881	10,242	2,788	2,894	2,017	2,026
2008	Jan	2,781	2,778	10,067	10,394	2,817	2,993	1,959	1,978
	Feb	2,505	2,645	9,057	9,656	2,507	2,570	1,774	1,807
	Mar	2,625	2,599	9,303	9,784	2,603	2,666	1,705	1,829
	Apr	2,600	2,697	8,890	9,565	2,490	2,625	1,727	1,731
	May	2,529	2,561	8,923	9,740	2,373	2,620	1,701	1,823
	Jun	2,507	2,679	8,864	9,295	2,408	2,643	1,798	1,872
	Jul	2,769	2,805	9,829	10,174	2,886	2,977	1,957	2,049
	Aug	2,915	2,995	9,958	10,287	2,791	2,892	1,930	2,050
	Sep	2,620	2,912	9,746	10,379	2,862	2,966	1,977	1,975
	Oct	2,693	2,789	9,675	10,108	2,772	2,808	1,839	1,961
	Nov	2,312	2,562	8,745	9,198	2,566	2,607	1,802	1,765
	Dec	2,816	2,852	9,570	10,238	2,813	3,013	1,933	2,005
2009	Jan	2,477	2,607	8,916	9,414	2,601	2,836	1,849	1,844
	Feb	2,380	2,365	8,426	8,879	2,389	2,451	1,674	1,688
	Mar	2,537	2,702	9,123	9,676	2,557	2,656	1,709	1,788
	Apr	2,471	2,580	8,661	9,101	2,520	2,542	1,648	1,662
	May	2,447	2,546	8,757	9,134	2,423	2,572	1,674	1,748
	Jun	2,602	2,627	8,675	9,107	2,626	2,779	1,685	1,815
	Jul	2,742	2,893	9,390	9,726	2,840	2,955	1,926	2,012
	Aug	2,668	2,815	9,448	9,734	2,852	2,961	1,871	1,951
	Sep	2,706	2,780	9,559	9,870	2,921	2,997	1,834	1,919
	Oct	2,535	2,680	9,270	9,673	2,789	2,787	1,713	1,887
	Nov	2,439	2,529	8,619	9,077	2,554	2,682	1,599	1,733
	Dec	2,721	2,626	9,399	9,760	2,756	2,927	1,793	1,879
2010	Jan	2,423	2,494	8,632	9,188	2,526	2,520	1,665	1,741
	Feb	2,250	2,367	8,039	8,367	2,263	2,392	1,514	1,539
	Mar	2,461	2,601	8,737	9,242	2,537	2,656	1,613	1,669
	Apr	2,243	2,419	8,174	8,556	2,364	2,347	1,526	1,577
	May	2,293	2,423	8,270	8,640	2,357	2,388	1,542	1,526
	Jun	2,341	2,500	8,434	8,775	2,507	2,613	1,582	1,676
	Jul	2,613	2,640	8,433	9,004	2,603	2,755	1,670	1,758
	Aug	2,573	2,709	9,071	9,588	2,706	2,834	1,801	1,799
	Sep	2,625	2,867	9,335	9,599	2,731	2,975	1,782	1,764
	Oct	2,484	2,550	9,206	9,605	2,566	2,786	1,609	1,711
	Nov	2,476	2,626	9,047	9,460	2,614	2,689	1,663	1,749
	Dec	2,445	2,627	9,416	9,772	2,791	2,859	1,676	1,884

Table 1 (continued)

Date		Alabama		Florida		Louisiana		Mississippi	
year	month	female	male	female	male	female	male	female	male
2011	Jan	2,385	2,564	8,626	9,112	2,410	2,620	1,594	1,688
	Feb	2,219	2,284	7,937	8,270	2,346	2,380	1,510	1,531
	Mar	2,329	2,558	8,462	8,822	2,421	2,623	1,586	1,652
	Apr	2,064	2,319	7,947	8,398	2,250	2,391	1,487	1,506
	May	2,222	2,413	8,046	8,727	2,370	2,508	1,534	1,584
	Jun	2,521	2,597	8,445	8,838	2,526	2,532	1,556	1,676
	Jul	2,582	2,646	8,965	9,323	2,624	2,757	1,669	1,780
	Aug	2,773	2,839	9,466	9,866	2,748	3,026	1,802	1,852
	Sep	2,465	2,662	9,293	9,898	2,709	2,808	1,779	1,729
	Oct	2,384	2,478	9,088	9,242	2,614	2,677	1,672	1,647
	Nov	2,412	2,497	8,850	9,295	2,579	2,692	1,644	1,760
	Dec	2,541	2,600	8,932	9,566	2,653	2,624	1,808	1,814
2012	Jan	2,374	2,436	8,569	8,886	2,546	2,582	1,648	1,592
	Feb	2,284	2,341	8,231	8,522	2,411	2,559	1,516	1,565
	Mar	2,210	2,389	8,512	8,996	2,414	2,620	1,527	1,482
	Apr	2,234	2,252	7,944	8,441	2,230	2,404	1,405	1,477
	May	2,358	2,425	8,321	8,802	2,430	2,563	1,559	1,535
	Jun	2,390	2,514	8,382	8,614	2,393	2,609	1,571	1,622
	Jul	2,485	2,656	8,846	9,215	2,693	2,903	1,689	1,790
	Aug	2,689	2,711	9,336	9,689	2,786	2,933	1,686	1,738
	Sep	2,428	2,495	9,003	9,664	2,691	2,814	1,601	1,654
	Oct	2,482	2,599	9,410	9,819	2,762	2,810	1,666	1,773
	Nov	2,448	2,482	8,615	9,135	2,526	2,646	1,651	1,663
	Dec	2,390	2,376	8,865	9,331	2,576	2,741	1,573	1,686

gistic model for a trend and a jump in 2006 [$boys_t \sim binomial(LB_t, \pi_t)$], where t is the time in months and LB is live births, has the following form:

$$\log odds (\pi_t) = a_0 + a_1 \times t + a_2 \times d_{2006} (t). \quad (1)$$

The dummy variable dAprJun2006 for a peak 8–10 months after Hurricane Katrina has the value 1 in April, May and June 2006, and the value 0 elsewhere. The simple but effective seasonal submodel employed has the form:

$$season (t) = a + b \times \sin(6.28 \times t + c) + d \times \cos(12.57 \times t + e), \quad (2)$$

where ‘a’ to ‘e’ are appropriately estimated parameters specific for the individual US states or combinations of states.

The analysis in this paper was multivariable. The model used contained 4 main parameters and 5 seasonal nested parameters [season (t), formula 2]. The explicit model equation in SAS notation is ‘model m/tot = t season_t dAprJun2006 rain’, with the variables: m = monthly male births; tot = monthly total births; t = time in months; season_t = seasonal submodel (formula 2, see above); dAprJun2006 = dummy variable for the time window from April to June 2006; rain = total amount of rain per state.

Data were processed with Microsoft Excel 10, and statistical analyses were carried out using SAS 9.3 (SAS Institute Inc., Cary, N.C., USA). A p value ≤0.05 was taken to represent a statistically significant result.

Results

Of the total 3,903,660 live births, 1,996,966 (51.16%) were male and 1,906,694 (48.84%) were female (M/F = 1.0473). Comparison of the overall monthly M/F trend in Alabama, Florida, Louisiana and Mississippi combined from 2003 to 2012 disclosed no obvious long-term disturbances after Hurricane Katrina. However, there was a significant seasonal variation (p = 0.0073), which means that the seasonal submodel (equation 2, above) significantly improved the fit of the ordinary linear logistic time trend model. Moreover, 8–10 months (April to June 2006) after the hurricane, M/F jumped significantly from 1.052 to 1.071 with a SOR of 1.018 (95% CI 1.005, 1.032, p = 0.0074; fig. 2).

The state of Mississippi was hit the hardest by rainfall during the passage of Hurricane Katrina (fig. 1). Comparison of the M/F trends of Florida, which experienced below 10 inches of precipitation during the storm, with Alabama, Louisiana and Mississippi combined, all of which experienced heavy rainfall of more than 10 inches (fig. 1; table 2), disclosed that in Florida no peak from April to June was present (SOR 1.002, 95% CI 0.984, 1.019, p = 0.8661; fig. 3), whereas a highly significant peak was evident in Alabama, Louisiana and Mississippi (SOR 1.042, 95% CI 1.021, 1.064, p < 0.0001; fig. 4). The SOR peak 4–6/2006 together with the 95% confidence intervals for all four individual states by the overall sum of rainfall in these states within the 3 days of the passage of Hurricane Katrina is displayed in figure 5. This monotone relationship suggests a possible causal relation between rain and an increase in M/F 8–10 months after exposure. A simple proportion calculation involving the additional M/F increase shown over 3 months in Alabama, Louisiana and Mississippi translated to a deficit of approximately 800 girls if, theoretically, only girls were affected by lethal mutations.

Table 2. Precipitation in inches for Alabama, Florida, Louisiana and Mississippi for the 3 days (29–31/8/2005) of the passage of Hurricane Katrina

Date	29/8	30/8	31/8
Alabama			
Count	6,221	8,673	3,988
Minimum	0.0	0.2	0.0
Maximum	5.2	10.3	1.6
Sum	1,475.8	14,417.9	452.6
Mean	0.2	1.7	0.1
Louisiana			
Count	4,864	5,480	535
Minimum	0.0	0.0	0.0
Maximum	10.4	10.5	0.8
Sum	8,631.2	6,916.0	20.7
Mean	1.8	1.3	0.0
Mississippi			
Count	5,730	8,015	1,103
Minimum	0.0	0.5	0.0
Maximum	8.2	10.3	2.1
Sum	3,821.1	27,155.5	96.9
Mean	0.7	3.4	0.1
Florida			
Count	8,856	8,138	7,377
Minimum	0.0	0.0	0.0
Maximum	3.0	3.9	4.1
Sum	2,920.8	3,234.3	1,918.2
Mean	0.3	0.4	0.3

The count is the number of readings. Minimum, maximum, sum and mean values are given as inches.

Discussion

In this study, there was a dose-response relationship between rainfall after Hurricane Katrina and the monthly M/F ratio of live births 8–10 months later. Rainfall generally increases the ambient background radiation, and radiation in turn is known to increase the sex ratio [15, 16]. Stress from any cause tends to lower M/F due to an excess male foetal losses [6, 9, 17].

This theory accords with the Trivers-Willard hypothesis, which proposes that evolution through natural selection has favoured individuals who are capable of biasing offspring gender in favour of the sex with the best reproductive prospects in accordance with extant periconceptional and gestational conditions [18–20].

It has been shown that Hurricane Katrina caused foetal loss which was dose-related to property damage [8]. Indeed, it has been estimated that the adjusted odds of foetal death were 1.4 and 2.4 times higher, respectively, in parishes suffering 10–50 and >50% wreckage to available housing stock [10]. For every 1% increase in the destruction of housing stock, the study showed a 1.7% increase in foetal losses [10]. The study does not support the Trivers-Willard hypothesis since the foetal losses that occurred shortly after Hurricane Katrina appeared to have affected both genders equally. However, an expected seasonal variation was found, as previously reported [11].

This study has shown a monotone relationship (a positive correlation) that could underpin a possible causal relation between rain or the radioactivity contained therein [21], and M/F 8–10 months after exposure. This was present only in the three states (Alabama, Louisiana and Mississippi) most affected by rainfall and floods. The distinct M/F peak could perhaps be explained by increased ionizing radiation exposure during and after the passage of Hurricane Katrina. Florida failed to show an M/F rise and this may be due to the much smaller amount of rainfall experienced in this state following the storm.

Radiation is a unique toxin in that when both genders within a population are equally exposed, an overall increase in M/F is produced since more females than males are lost in utero from lethal mutations [15]. This is because irradiated men sire an excess of males [22] and irradiated females give birth to an excess of females [23, 24].

These findings are attributed to the hypothesis that if an X-linked recessive lethal gene is induced in a mother's germ cell line by ionizing radiation, it would have no effect on a heterozygous daughter but would be lethal to a hemizygous male zygote. X-linked dominant lethal mutations in mothers would be equally lethal to both genders [23]. X-linked dominant mutations induced in fathers

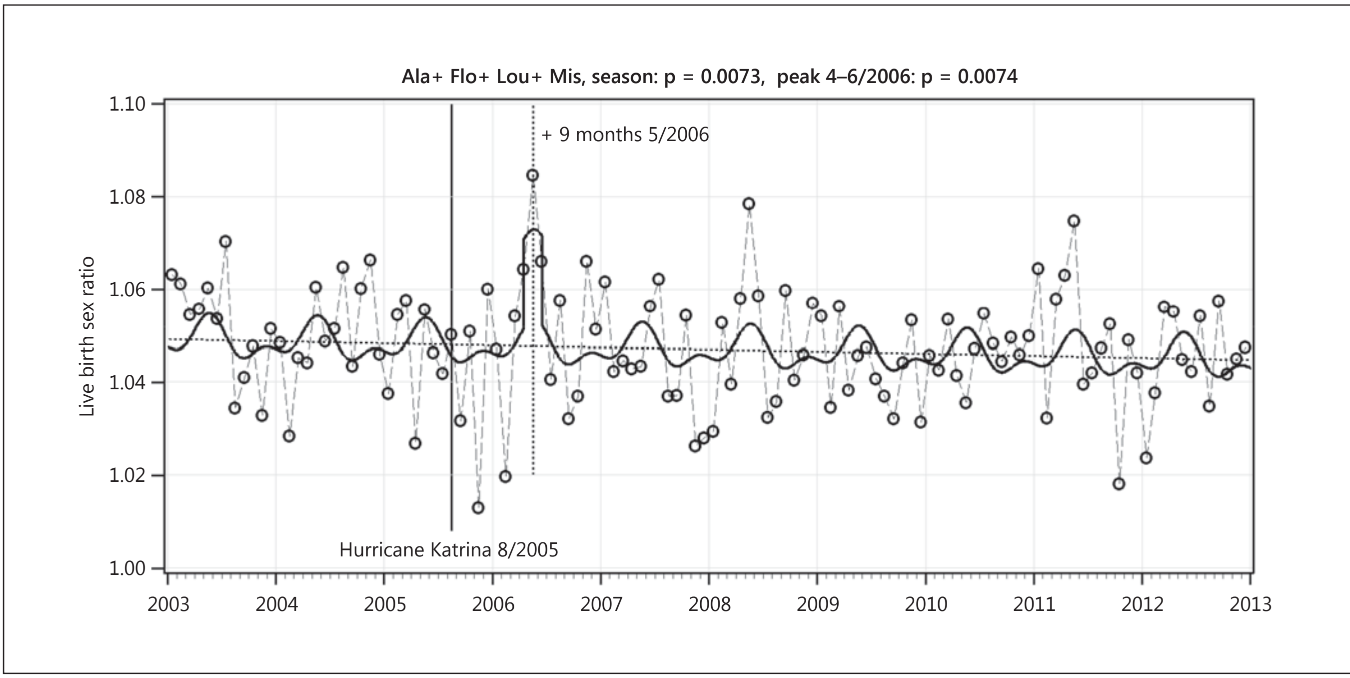

Fig. 2. The M/F trend in Alabama (Ala), Florida (Flo), Louisiana (Lou) and Mississippi (Mis) combined from 2003 to 2012: seasonal ordinary linear logistic regression model (equation 2) with a significant peak between April and June, 2006 (peak 4–6/2006), 8–10 months after Hurricane Katrina.

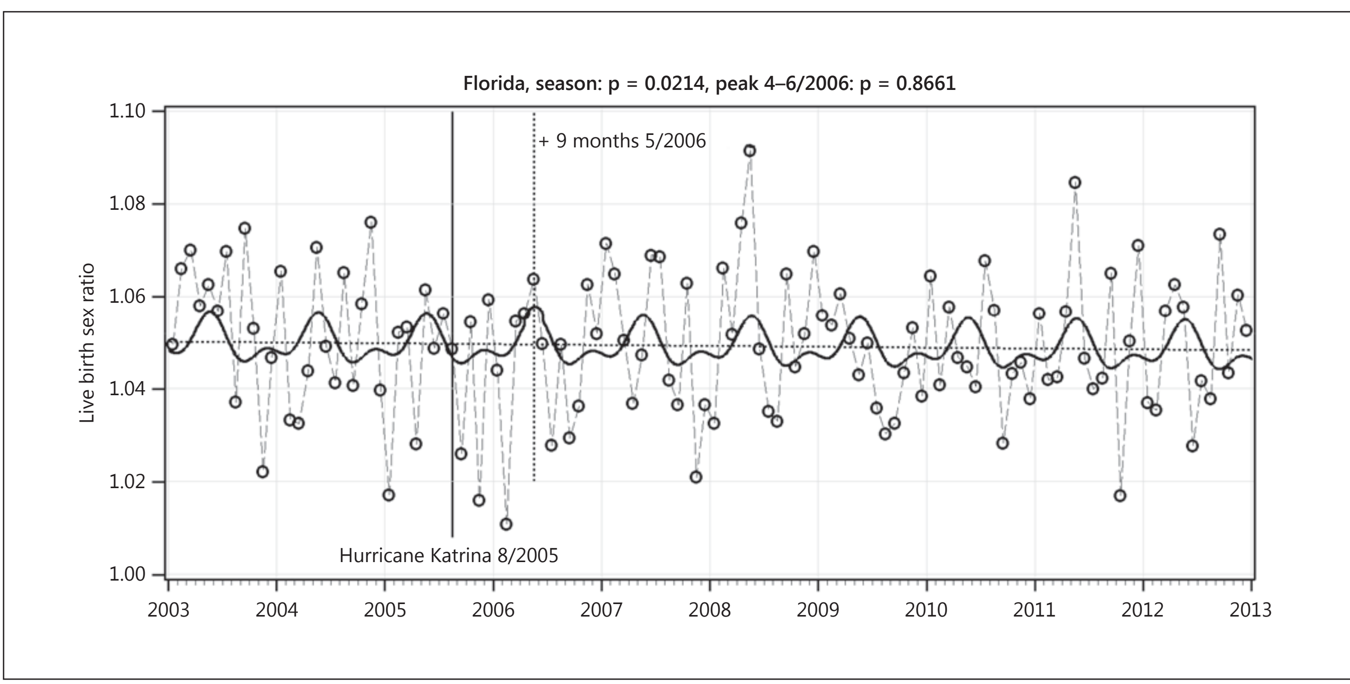

Fig. 3. The M/F trend in Florida from 2003 to 2012: seasonal model (equation 2) with a non-significant peak between April and June, 2006 (peak 4–6/2006), 8–10 months after Hurricane Katrina.

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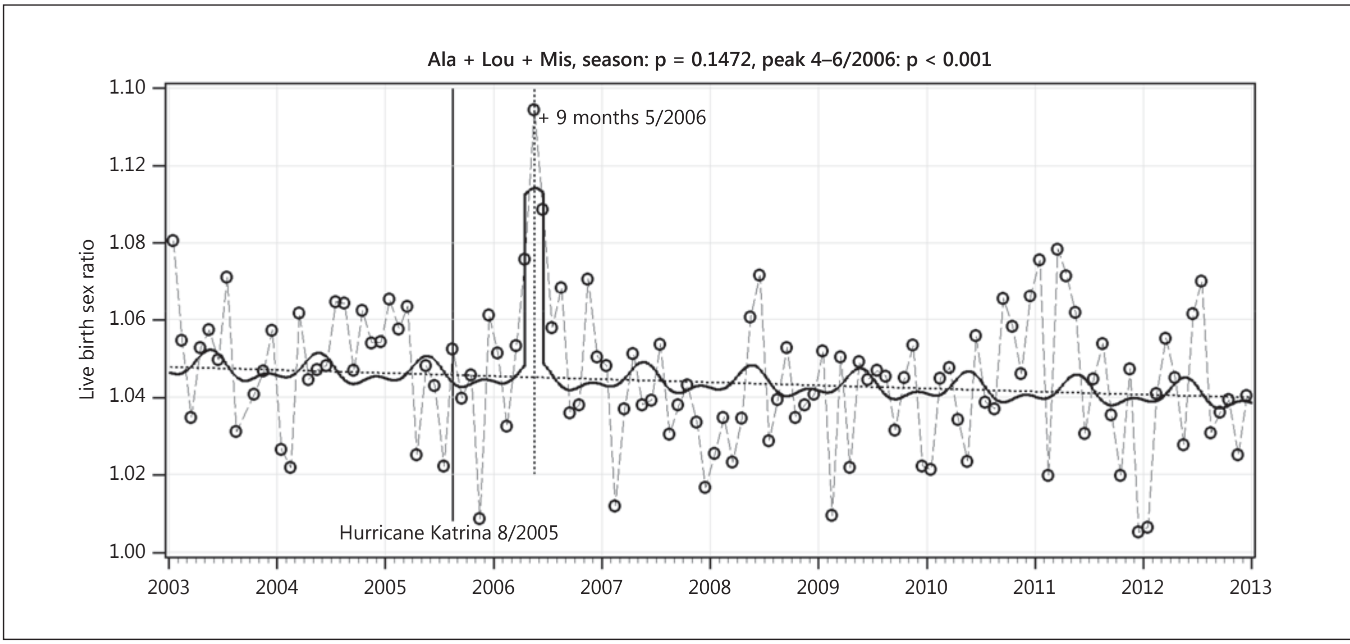

Fig. 4. The M/F trend in Alabama (Ala), Louisiana (Lou) and Mississippi (Mis) combined: seasonal model (equation 2) with a highly significant peak between April and June, 2006 (peak 4–6/2006), 8–10 months after Hurricane Katrina.

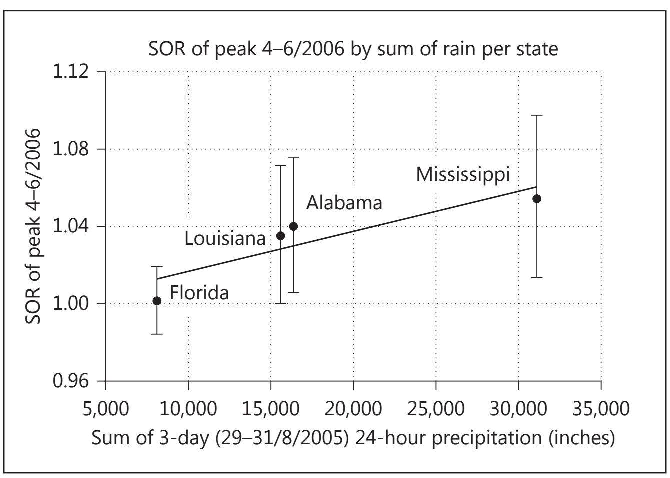

Fig. 5. Monotone association between the peak SOR (including 95% CIs) between April and June 2006 and total rainfall over Florida, Louisiana, Alabama and Mississippi from August 29 to 31, 2005.

would only suppress female offspring. Recessive X-linked lethal mutations in fathers would not influence the gender ratio as sons do not receive the paternal X chromosome and daughters carry (and are protected by) a second X chromosome from their mother [23]. The sex ratio is therefore influenced by an increased but gender-biased foetal mortality.

It has been hypothesized that the skew toward higher female mortality may be due to the fact that the X chromosome contains more genetic material and is larger, and hence may be physically more easily struck by ionizing radiation. Another possibility is that ova and sperm afford their genetic material different levels of protection [16, 23].

It has long been known that rainfall is positively associated with a rise in M/F [12]. It is also known that rainfall is associated with an increase in ambient natural background radiation due to the precipitation of radionuclides [21]. This study appears to confirm this relationship through the induction of a female birth deficit after heavy rainfall.

Conclusion

This study showed that heavy rainfall and flooding following Hurricane Katrina in the three states most affected were associated with a subsequent rise in M/F. As rain increases background radiation, and radiation increases M/F, we are, to the best of our knowledge, the first to suggest that the well-known yet unexplained sex ratio seasonality may be at least partially due to natural or manmade radiation contained in precipitation.

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