

Divergences in trends in child and adult mortality in sub-Saharan Africa: Survey evidence on the survival of children and siblings

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Abstract

We provide an overview of trends in mortality in children aged under 5 and adults between the ages of 15 and 60 in sub-Saharan Africa, using data on the survival of the children and siblings collected in Demographic and Health Surveys. If conspicuous stalls in the 1990s are disregarded, child mortality levels have generally declined and converged over the last 30–40 years. In contrast, adult mortality in many East and Southern African countries has increased markedly, echoing earlier increases in the incidence of HIV. In recent years adult mortality levels have begun to decline once more in East Africa, in some instances before the large-scale expansion of antiretroviral therapy programmes. More surprising is the lack of sustained improvements in adult survival in some countries that have not experienced severe HIV epidemics. Because trends in child and adult mortality do not always evolve in tandem, we argue that model-based estimates, inferred by matching indices of child survival onto standard mortality schedules, can be very misleading.

Keywords: mortality estimation; sub-Saharan Africa; adult mortality; child mortality; siblings; HIV/AIDS

1. Introduction

Trends in child and adult mortality are important markers of progress in the health of populations, and these are best monitored through comprehensive vital registration systems. However, the vital registration systems operating in the vast majority of African countries fail to provide full national coverage. With the exception of South Africa and, until recently, Zimbabwe, less than 25 per cent of deaths are reported in the official records of mainland sub-Saharan Africa and Madagascar (Dorrington et al. 2001; Feeney 2001; Mathers et al. 2005). As a result, our understanding of the health transitions in this region, particularly when considering the experience of adults, is largely based on model life tables (MLTs).

The Population Division of the United Nations (UNDP) produces model-based estimates of mortality which are widely used. They are obtained in two or, in some cases, three steps (United Nations 2011). First, for each country, a smooth trend in child mortality is derived from data collected by censuses and large-scale surveys (Hill et al. 2012). Second, the derived trend is matched to MLTs to obtain a complete set of age-specific mortality rates for the population not infected by HIV, thus obtaining rates of 'background' mortality. This procedure is followed for about 40 countries in sub-Saharan Africa. In those countries where HIV prevalence has ever reached 2 per cent of the population aged 15–49, a third

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step is taken: the impact of the epidemic is factored in by adding estimates of AIDS-related deaths in an ad hoc fashion, taking AIDS-related deaths from an epidemiological model which uses HIV prevalence estimates as inputs (Stover et al. 2010). The resulting mortality rates for each country are compared with alternative estimates derived from the country's vital registration system, surveys, censuses, or health and demographic surveillance sites (HDSS). If a substantial discrepancy is found between the various estimates, the estimate of background mortality is revised and the procedure is repeated until a "reasonable agreement" is achieved (United Nations 2005).

The UNPD mortality estimates are continuously refined in a manner that ensures that they are consistent both with other components of the prevailing demographic regime and with well-established age patterns of mortality (United Nations 2005). The relationship between child and adult mortality in any particular scenario is, however, constrained by the model life table selected and the assumptions made when reconstructing the course of the HIV epidemic.

Here, we present an overview of trends in child and adult mortality in sub-Saharan Africa without resorting to model life tables. Instead we use birth and sibling histories, collected as part of a number of Demographic and Health Surveys (DHS), and adopt comparable methods to obtain each set of estimates. This approach has the significant advantage of allowing us to evaluate how age patterns of mortality have changed over time. After a description of the estimation method used, we present trends in the two mortality indices ${}_5q_0$ and ${}_{45}q_{15}$. The first index, ${}_5q_0$, also referred to as 'the under-five mortality rate', indicates the probability, given the mortality regime of the year under consideration, that a newborn will die before reaching its fifth birthday. Similarly, the index ${}_{45}q_{15}$ represents the probability that a person aged 15 will die before reaching his or her sixtieth birthday if faced with the mortality rates prevailing at each age in the year observed. The presentation of the trends is followed by a discussion of changes in age patterns of mortality.

2. Data and methods

2.1. *Estimating child mortality*

Various types of retrospective reports on child survival can be used to compensate for a lack of vital registration data. Modern censuses in developing countries typically collect summary birth histories (SBHs), that is, the number of children ever born to women of reproductive age and the number of those children surviving at the date of the census. From SBHs, indirect estimates of mortality can be obtained using Brass's method or one of its variants (Brass et al. 1968; Sullivan 1972; Hill and Figueroa 2001). Although these indirect methods can be applied to DHS data, we did not use them because it is unclear how SBHs should be adjusted to account for the underreporting of deaths. In order to establish a time period to which these estimates refer, a steady and unidirectional change in mortality has to be assumed, resulting in mortality trends which are excessively smoothed (Silva 2012). Rajaratnam et al. (2010a) developed alternative methods whereby the births and deaths reported by women of a specific parity and age, or time since first birth, are allocated across the years preceding the survey. These methods circumvent some of the limitations of the original approach, but they cannot capture rapid fluctuations in mortality. This is because the expected distributions of births and deaths in the years preceding a survey have to be generalized from figures taken across a range of countries and periods.

In contrast to the methods outlined above, our estimates make use of full birth histories (FBHs), collected by DHSs. Each history is an exhaustive enumeration by the mother of all her children, giving for each the sex, date of birth, survival status, and current age or age at death. Additional questions locate surviving children within the roster of household members and identify multiple births. We used

data from 107 DHSs conducted between 1986 and 2011 and covering 36 sub-Saharan countries. Only four countries in the region with populations numbering over two million in 2013 were omitted, because no DHS had been conducted or distributed in public domain: Botswana (2.1 million), Mauritania (3.7), Eritrea (5.7), and Somalia (10).

The DHS datasets were reformatted to obtain the total number of deaths and exposure time for each combination of age, sex, calendar year, and time preceding the survey (as explained in the appendix to this paper which is provided below). The data were pooled within each country and mortality estimates were obtained using a Generalized Additive Model (GAM). GAMs extend generalized linear models by adding a sum of smooth functions of covariates to the linear predictor (Hastie and Tibshirani 1986; Wood 2006). The parametric part of the GAM model included the child's age (specified as either 'less than one' or 'one to four') interacted with sex. For the 26 countries that had more than one DHS with full birth histories, both the age pattern of mortality and any differentials by sex were allowed to change linearly over time. The number of deaths was assumed to follow an over-dispersed Poisson distribution, with the log of exposure time as an offset parameter. Deaths and exposure time occurring more than 22 years before each survey were discarded. Trends in mortality were smoothed using thin plate regression splines (Wood 2003). The degree of smoothing was selected as part of the fitting of the model by minimizing the generalized cross-validation score (GCV). We refer the reader to Wood (2006) for an in-depth discussion of GAMs and to the appendix (below) for further details of the methods used.

In recent years, research into the estimation of trends in child mortality has been expanded to a notable extent by work undertaken by both the UN Inter-agency Group for Child Mortality Estimation (IGME) (Hill et al. 2012) and the Institute for Health Metrics and Evaluation (IHME) (Lozano et al. 2011). There are, however, substantial discrepancies between IGME and IHME estimates, for three reasons: differences in the way the databases used were constructed; differences in the criteria used to include or reject some data series; and, to a lesser extent, differences in the trend-fitting methods deployed (Alkema and You 2012). There are also differences between our estimates and those developed by IGME and IHME. In addition to the fact that we used only full birth histories, we adjusted mortality rates upwards to account for the underreporting of deceased children, relative to the reporting of those who had survived.

DHS questionnaires contain lengthy sections on pregnancies, postnatal care, nutrition, immunizations and child health. These sections apply only to births that occurred after a particular cut-off date, usually the first of January of the fifth calendar year preceding the survey. To reduce their workload, some interviewers learn to omit births, or to 'transfer' some births backwards in time, so that they appear to occur before the cut-off date. Mothers might also fail to report all births, particularly in high-fertility settings, and may omit births that occurred in the distant past, especially if the child died at an early age. These problems can distort the fertility rates and trends derived from the data (Schoumaker 2009). Inevitably, they will also affect mortality estimates (Johnson et al. 2005). Various strategies have been used to account for 'transferred' births (Rajaratnam et al. 2010b), but little headway has been made to address the issue of omitted births. We estimated the extent of transference and omission by pooling all the data we had from the DHS, and comparing mortality rates from successive surveys for a fixed reference period (Pullum 2006). Mortality rates were obtained for children under the age of one and those aged one to four from a Poisson regression. Sex and 'time period', expressed in five-year intervals (1980–84, 1985–89, etc.) were included as covariates, interacted with country dummies. The 'time preceding the survey' (TIPS) was introduced as a set of indicator variables, one for each completed year. The exponentiated coefficients for the TIPS provided the mortality rate ratios displayed in the upper panel of Figure 1. The reference category 'seven completed years' (that is, seven to eight exact years before the survey) was chosen. This was earlier than, but not before, the cut-off date.

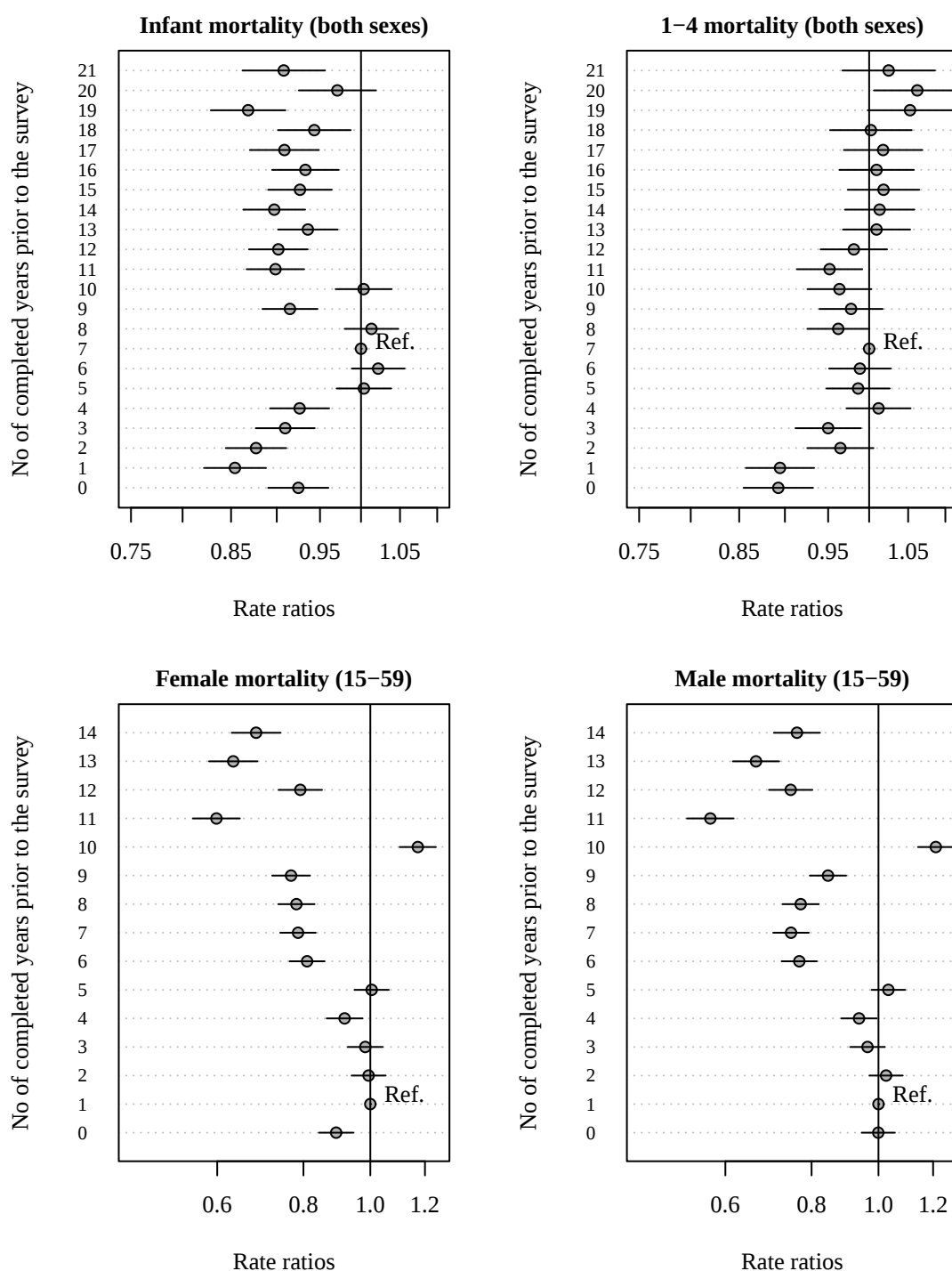


Figure 1 Mortality rate ratios associated with each completed year prior to the DHS; sub-Saharan Africa. Upper panels: Infant mortality and mortality of children aged 1-4 years (reference category: 7 to 7.9 exact years before the DHS). Lower panels: Mortality of adults aged 15-59, by sex (reference category: 1 to 1.9 exact years before the DHS). Source: Birth and sibling histories from Demographic and Health Surveys (DHS). Estimates based on 95 DHS for children and 58 DHS for adults.

Figure 1 suggests that deaths in the years immediately prior to the surveys were subject to significantly more underreporting than those taking place in the reference period. The mortality rate ratio for infants in the period one to two exact years before each survey is as low as 0.85, which means that 15 per cent more infant deaths were either unreported or ‘transferred’ than in the reference period. This is

consistent with the belief that a disproportionate number of deceased children were omitted by interviewers in order to avoid having to complete the additional health questions. The omission of a deceased child would not reduce the length of the interview as much as omitting a surviving child, but was probably easier to 'get away with' because surviving children were likely to have been reported in the list of household members.

Figure 1 also indicates that the further back in time the period, the more the reporting of infant deaths declines relative to the reference period. On average about ten per cent of infant deaths occurring more than eleven completed years before each survey went unreported. This pattern is not observed in children aged one to four, which could be because recall of age at death is less precise as time goes by and therefore a growing fraction of infant deaths were reported as occurring at age twelve months or more.

To correct for the possible misrepresentation of child mortality levels and trends because of the underreporting of deaths, we multiplied the number of deaths in each time period by the reciprocal of the rate ratios associated with the TIPS. This method assumes that deaths occurring seven to eight years preceding the survey are accurately reported. If deaths were omitted by a constant factor, irrespective of the TIPS, the adjusted mortality rates would remain biased.

Because interviews can be conducted only with surviving mothers, downward bias in mortality can also occur if children who have lost their mother are at greater risk of dying than those whose mother survives. This bias has long been deemed negligible, but has become a concern in countries with high HIV prevalence because of the risk of transmission of the virus from infected mothers to their children during pregnancy, delivery or breastfeeding. The IGME explicitly accounts for the possibility of such transmission by adopting the cohort-component projection model detailed in Walker et al. (2012). We used their method to adjust our mortality rate estimates. For most countries the bias was estimated to have been relatively modest, reducing mortality rates for those aged under five by one per cent on average in 1990 and by seven per cent in 2000. Zimbabwe was an exception: we calculated that the bias there resulted in the under-five mortality rate being underestimated by 28 per cent in 2000. It should be noted that this correction procedure is underpinned by strong assumptions, including the absence of antiretroviral therapy (ART). It also requires that the level of non-AIDS child mortality be selected somewhat arbitrarily. Plots of estimates of ${}_5q_0$ for each country with and without the 'HIV correction' are presented in Figure S2 in the Appendix.

2.2. *Estimating adult mortality*

Since 1988 some DHSs have included a module on maternal mortality that includes a standard set of questions designed to elicit an exhaustive list of all the children born to the interviewee's mother. The information collected on each member of this 'maternal sibling group' includes birth order, sex, and survival status. Current age is recorded for surviving siblings, while age at death and years since death are collected for those who have died. Additional questions identify sisters who died from pregnancy-related causes.

In less developed countries, these 'sibling histories' are now a cornerstone of the estimation of maternal and all-cause adult mortality (Hogan et al. 2010; Rajaratnam et al. 2010c; Reniers et al. 2011; Wilmoth et al. 2012a). The Global Burden of Disease Study 2010 (GBD), led by the IHME, made extensive use of sibling histories to estimate mortality rates for countries in sub-Saharan Africa (Wang et al. 2012). The GBD estimates were derived using a three-stage process. First, a linear model was used to relate measurements of ${}_5q_0$ and ${}_{45}q_{15}$ to education, lagged gross domestic product per capita, and crude death

rates due to AIDS as estimated by the Joint United Nations Programme on HIV/AIDS (UNAIDS). Second, the residuals from the first stage were smoothed across countries and time. The third stage comprised a Gaussian process regression to combine the data, the sampling and non-sampling variation, and the information from the first two stages to yield final estimates and uncertainty intervals for each country. GBD estimates of adult mortality are not as closely linked to child mortality as is the case for the UNPD estimates, but they are related to a common set of covariates and these covariates are themselves based on extensive modelling. Therefore, while the GBD approach is useful when generating estimates for countries with sparse data, it is not totally adequate when analysing joint changes in mortality among adults and children.

In a study based on 26 DHSs, Timaeus and Jasseh (2004) used a more straightforward approach to model adult mortality from DHSs. They pooled all sibling histories in a single Poisson regression, including a standard age pattern, to smooth non-AIDS mortality rates and additional parameters to allow for mortality increases due to AIDS. Only three of the countries included in their study had more than one set of sibling histories. In our study, we used 72 DHSs, covering 34 countries. A smaller number of DHSs could be used for adult mortality (compared with child mortality) because not all surveys include a maternal mortality module. Deaths and exposure time that predated each survey by twelve years or more were discarded. For 20 of the 34 countries, at least two sets of sibling histories were available. The latter allowed us to fit separate models for each country, using penalized thin-plate regression splines to refine the smoothing of trends. The age pattern of mortality and sex differences were also allowed to change linearly with the duration of each country's HIV epidemic, starting four years after the calendar year in which the UNAIDS (2012) HIV prevalence estimate for that nation reached 2 per cent. This four-year period corresponds approximately to the lag between the development of an HIV epidemic within the general population and the emergence of the resulting changes in adult mortality rates (Notkola et al. 2004). In cases where only one DHS was available, we used an over-dispersed Poisson regression, assuming a constant rate of change over the twelve-year period, and including dummies for age group and sex.

Because previous research has shown that respondents tend to underreport deceased siblings (Obermeyer et al. 2010; Reniers et al. 2011), we used an adjustment comparable to that used in the estimation of child mortality discussed above. We pooled all deaths and exposure time for those periods covered by at least two DHSs, and introduced the TIPS as a set of indicator variables in a Poisson regression model controlling for trends and variations in age patterns of mortality. Because the structure of the maternal mortality module in the DHS does not induce interviewers to disproportionately displace or omit recent deaths, the reference TIPS category was set as one to two years preceding the survey. As is clear in the lower panel of Figure 1, which shows mortality in the 15-59 age group, the decline in the completeness of death reporting as the interval between death and survey increases is more rapid in this age group than among young children. Compared to the reference period, male deaths are significantly underreported for periods that precede the survey by three years or more. There is also distinct heaping at ten years prior to the survey, indicating that respondents had difficulty recalling how many years had passed since a sibling's death. Mortality rates were again adjusted by the reciprocal of the rate ratios. We reiterate that this only corrects for underreporting that is correlated with the time preceding the survey.

3. Trends in child mortality

A summary plot of trends in under-five mortality by country, within region, is presented for both sexes combined, using a log scale. The geo-spatial variation in ${}_5q_0$ for the 1980s, 1990s and 2000s is displayed in Figure 3. Country-specific trends for the years from 1970 to 2010 can be found as Figure S2 in the Appendix. A comparison of Figures 2 and 3 reveals three general trends: (i) child mortality declined in most, but not all, countries between 1970 and 2010; (ii) there was a convergence in under-five mortality rates over this period; and (iii) geographical differences in under-five mortality continue to persist, with the highest levels in West Africa and the lowest levels in East and Southern Africa. Let us first present the general features of these trends, before we describe the exceptions.

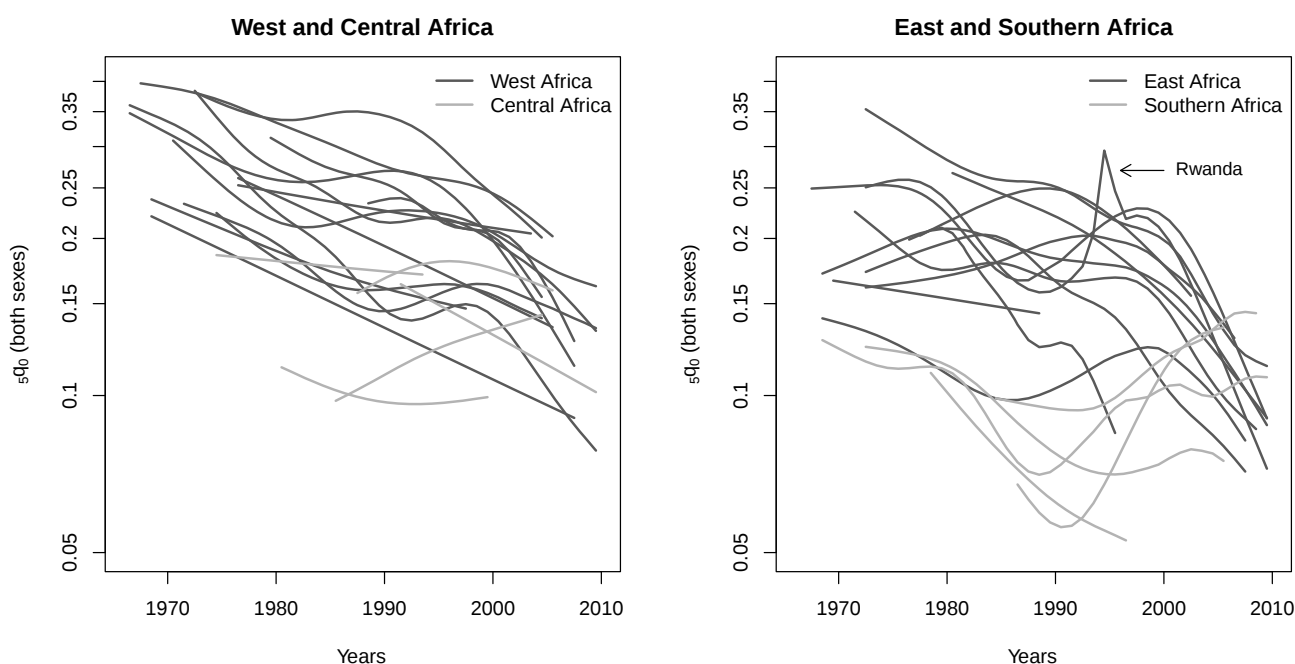


Figure 2 Trends in ${}_5q_0$ by country for both sexes combined; regions of sub-Saharan Africa, 1966–2009.
Source: Birth histories from DHS surveys (with adjustment for HIV-related biases: see text).

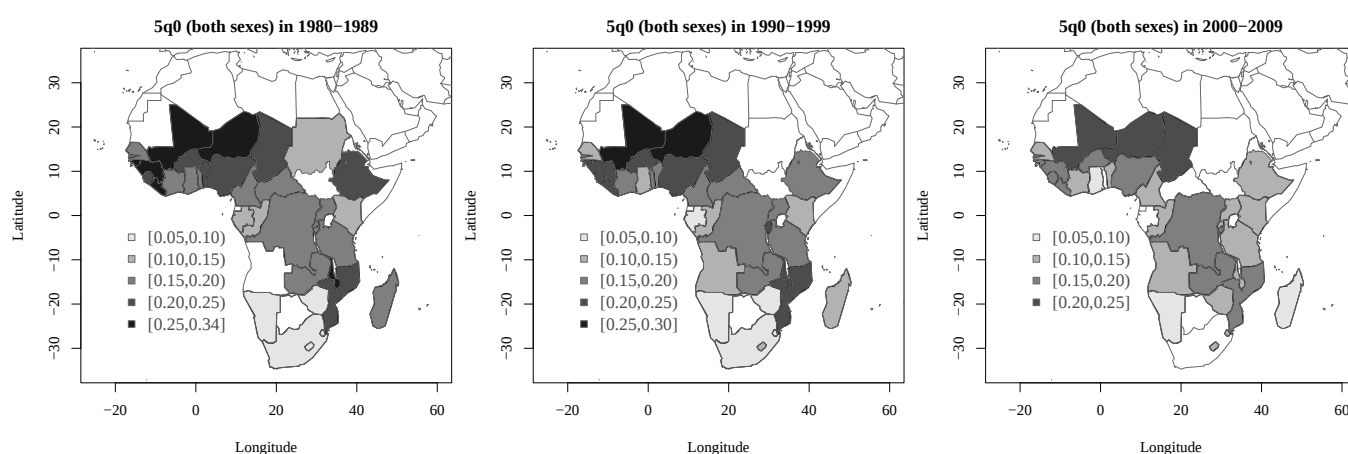


Figure 3 ${}_5q_0$ for both sexes combined, by country; sub-Saharan Africa 1980-2009.

Note: The values plotted on the maps refer to the average of available estimates for each country during the relevant decade. Source: As for Figure 2.

Under-five mortality declined from the 1970s to the 2000s in most countries in sub-Saharan Africa. In the 1970s, more than 20 per cent of children died before reaching their fifth birthday (a rate of 0.20 deaths for every birth) in the majority of countries; it was rare to find countries with an under-five mortality rate below 0.13. The median level of ${}_5q_0$ was close to 0.21. By the mid-2000s, very few countries had a mortality rate above 0.20 and the median rate was close to 0.14. Even though there had been a marked decline, the latter value was still roughly twice the average rate for South Asia (for 2005) and more than 15 times higher than the rates found in industrialized countries (Hill et al. 2012).

Year	West and Central Africa				East and Southern Africa			
	Min	Max	Median	N of countries	Min	Max	Median	N of countries
1975	0.185	0.364	0.248	11	0.113	0.323	0.183	11
1985	0.098	0.348	0.199	16	0.076	0.258	0.17	16
1995	0.097	0.296	0.176	18	0.054	0.246	0.168	16
2005	0.095	0.202	0.147	11	0.075	0.142	0.116	13

Table 1: Levels and trends in ${}_5q_0$ by region and period; sub-Saharan Africa, 1975-2005.

Source: As for Figure 2.

The declines in ${}_5q_0$ were most pronounced in West African countries. In contrast, child mortality rates appeared to increase in a handful of Southern African countries. Because West African countries had the highest levels of child mortality in the 1970s, and Southern African countries the lowest, the changes over the three decades resulted in a convergence in the levels of ${}_5q_0$. This finding is consistent with the trend across the decades preceding those presented here described by Hill (1993). One of the more striking features of the 2000s decade is that Southern African countries no longer stand out as having comparatively low child mortality rates. Before 1985, the countries with ${}_5q_0$ below 10 per cent were those in Southern Africa and Kenya in East Africa. By 2010 populations with low child mortality could be found in all regions. Geographical contrasts persist, however, with a gradient in ${}_5q_0$ across the continent from northwest to southeast. The landlocked Sahelian countries, such as Mali and Niger, always were and continue to be characterized by some of the highest levels of child mortality in the world.

Despite the overall convergence, some aberrations and irregularities are noteworthy. (i) In Southern Africa, the values of ${}_5q_0$ declined in the 1980s, but increased across the later 1990s and 2000s. (ii) In Central Africa, levels of child mortality did not change much between the 1980s and the 2000s. However, only a few surveys were available from which trends could be ascertained and their quality is questionable. Our estimates do not suggest a uniform pattern within Central Africa: child mortality levels remained high in the Democratic Republic of Congo, which recorded a ${}_5q_0$ of around 0.16 in 2005; they stagnated at a relatively low level in Gabon; in the Congo they seem to have increased from relatively low starting values. Angola is the only country in Central Africa which experienced a relatively rapid decline during the 1990s and 2000s. (iii) In West Africa, more surveys per country were available, allowing more reliable trends to be reconstructed. These indicated that child mortality declined substantially in all countries in West Africa during the 1970s. The decline then underwent a temporary slowdown, or even a reversal, in some countries during the 1980s and 1990s before accelerating once more during the 2000s. (iv) In East Africa, there was also a rapid decline in child mortality during the 2000s, following three decades of disparate trends: a succession of decreases and increases in Burundi, Kenya, and Rwanda; an increase followed by a decrease in Uganda, Madagascar, Mozambique, and Zambia; and a continuous decrease in Malawi and Ethiopia.

The factors underlying these trends are very diverse. Progress in infrastructure and in the provision of health programmes contributed to the spread of preventative measures, such as vaccination, and effective treatments reduced the impact of the infectious diseases responsible for most childhood deaths. The introduction of measles vaccine in Africa in the late 1970s and early 1980s, for example, coincided with major reductions in child mortality. Because the latter mortality declines were too large to be explained by the prevention of measles alone, the notion emerged that vaccines may have non-specific effects on the immunity and survival of children more generally (Aaby et al. 1995). Impressive gains in school enrolment also played an important role in enabling all sections of the population to benefit from the improvement in health services. On the other hand, in some countries socio-political instability, war, and the emergence of new diseases or the re-emergence of old ones, may have acted to counterbalance any positive influences.

The factor that immediately springs to mind as adversely affecting child mortality in the decades we studied is the HIV/AIDS epidemic. According to Marston et al. (2005), in the absence of other causes of death, only 39 per cent of children infected with HIV at birth survive to age five. Even uninfected children born to seropositive mothers experience excess mortality because their mother's illness or death may be detrimental to their nutrition and care (Zaba et al. 2005). HIV-driven reversals in the levels of $5q_0$ occurred in the second half of the 1980s in Kenya and Zambia, in the early 1990s in Zimbabwe, and even later in Namibia and Lesotho. In other countries, where child mortality was still quite high when the epidemic escalated, the impact of HIV/AIDS was often less visible because other factors were operating to reduce mortality. This was probably the case in Malawi, which experienced a continuous decline in child mortality, with only a slight slowdown in the 1980s, despite an HIV/AIDS epidemic of a similar magnitude to that in Zambia.

A second set of factors underlying the mortality reversals that characterize some countries was economic, social, and political turmoil and, in some cases, warfare. For example, the increase in child mortality in Uganda in the 1970s was probably related to the civil war and the collapse of the economy; later it would be exacerbated by the HIV epidemic. The civil war that followed independence in Mozambique also coincided with an increase in child mortality at the end of the 1970s and during the 1980s. The Rwandan genocide of 1994 is clearly visible in the right-hand graph of Figure 2 as a sharp spike in child mortality rates. Because this spike was apparent in the raw rates, we removed the 1993–95 period from the GAM model and estimated under-five mortality rates for this period from a simple quasi-Poisson regression, with each of the three years included as a dummy variable.

A slowdown or reversal of child mortality trends in the 1980s and 1990s also occurred in several countries that did not experience explicit economic, social, or political crises. This was the case for several countries in West and Central Africa, such as Burkina Faso, Liberia, Nigeria, and Senegal—none of which had to deal with a severe HIV epidemic either. The decline in child mortality resumed in most of these countries by the end of the 1990s or the early 2000s. Some authors have argued that these slowdowns were due to structural adjustment programmes which imposed reductions in government spending on health and education (Cornia et al. 1987), but there is little evidence to support this claim (Behrman 1988). Other factors may have played a role, as the case of Senegal suggests (Pison et al. 2012). HIV prevalence in Senegal never exceeded 1 per cent of the adult population (Ndiaye and Ayad 2006; ANSD 2012) and the country benefited from a relatively stable political climate, yet trends in the rate of child mortality were nonetheless irregular. After a rapid decline from the mid-1970s to the end of the 1980s, child mortality rates stalled or, on occasion, increased during the 1990s, but rapidly decreased after the turn of the century.

Senegal's pattern of child mortality decline resembles that found in many sub-Saharan African countries over the same period, but is unusual in the data sources that exist there for the monitoring of national trends in child mortality. In addition, three rural Health and Demographic Surveillance Sites (HDSS) have been in operation in the country for almost 25 years. These closely monitor all vital events occurring in the community under study and each death is usually followed by a 'verbal autopsy' interview in order to determine the underlying cause.

Trends in child mortality observed at the three Senegalese HDSSs, at Bandafassi, Mlomp and Niakhar, are comparable to those for the country as a whole (Figure S6, Appendix). The decline in child mortality in the 1970s and 1980s at the three HDSSs has been ascribed to a reduction in mortality from infectious diseases, such as measles, as a result of large-scale vaccination campaigns (Desgrées du Loû et al. 1995; Pison et al. 1995). During the 1990s, however, vaccination coverage reached a plateau and deaths from measles failed to decline further. Another reason for the failure to make progress in the 1990s was malaria. Figure S6 presents trends in the malaria-related mortality rate in children under the age of five in Mlomp and Niakhar. Deaths from malaria were identified from verbal autopsy data and by laboratory tests in Mlomp. The substantial mortality increase observed during the 1990s was identified as being directly associated with the spread of chloroquine resistance in the malaria parasite (Trape et al. 1998; Trape et al. 2012). Similar patterns were seen at all three HDSSs and help to explain the national-level trends in Senegal. In the 2000s a renewed commitment to vaccination and increased investments in new anti-malaria programmes were among the factors which contributed to a resumption of the decline in Senegal's child mortality rates. In sub-Saharan Africa as a whole, vaccination coverage also increased in the new century, after a decade of stagnation. For example, having declined from 56 per cent among 1-year olds in 1990 to 51 per cent in 1999, measles vaccination coverage then increased to 75 per cent in 2010 (UNICEF/WHO, 2012).

We find close agreement between our estimates and those developed by the IGME and the IHME for countries which have several DHSs available, such as Benin, Chad, and Liberia. Our $_{5q0}$ values are only four and eight per cent higher than those of the IGME and IHME respectively. The difference between the three sets of figures can be explained by our corrections to compensate for underreporting and any HIV-related bias; the IHME did not take any account of the latter. In countries with only one DHS, there is a greater discrepancy between our estimates and those of the IGME and IHME. In Angola, for instance, our estimates are much lower than those of the IGME, but the latter figures were based solely on summary birth histories which had been collected before the Malaria Indicator Survey conducted in 2011, which was the only dataset we had available for Angola. The 2008 DHS in Sierra Leone was not included in the IGME modelling exercise, presumably because the results it generated were at odds with indirect estimates from the MICS and the 2004 census (this can be seen in the IGME database, which is publicly available at www.childmortality.org). In Congo, there is also a dearth of data on mortality, and the declining trend in the IGME estimates is driven by the comparison of results from the DHS, conducted in 2005, with indirect estimates derived from the 1974 census. In Swaziland, our estimates for the 1990s are probably too low; they are not consistent with estimates based on the 1997 census results nor with those of the MICS conducted in 2000.

4. Trends in adult mortality

Figure 4 consists of two summary plots of trends in adult mortality in the countries of sub-Saharan Africa by region. Figure 5 presents the geographical distribution of $_{45q15}$ for the 1980s and the two succeeding decades. More detailed graphs of the trends in individual countries are provided in the Appendix (Figure S4). Three general patterns can be discerned from these plots, and these tend to

diverge from the earlier observations on child mortality. In the majority of countries adult mortality either stagnated or increased over the three decades shown. There was increasing heterogeneity in the levels of adult mortality observed, and over time the countries with the highest adult mortality levels became noticeably more concentrated in East and Southern Africa.

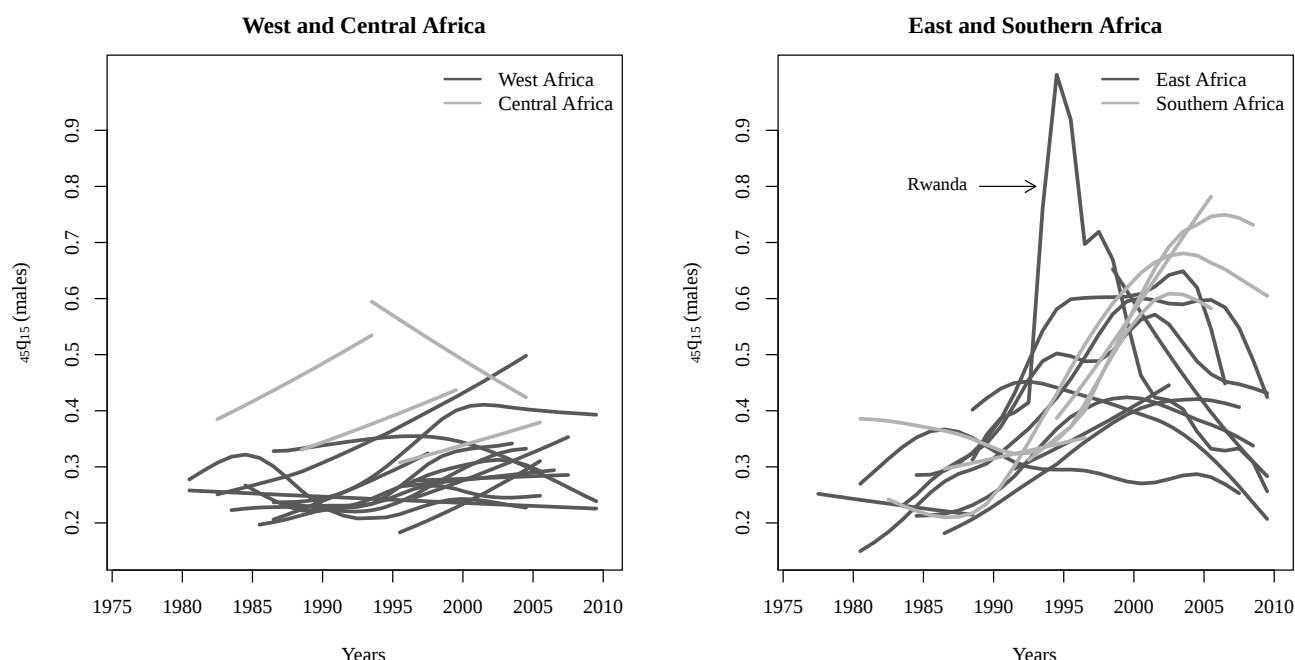


Figure 4 Trends in $_{45}q_{15}$ for males by country; regions of sub-Saharan Africa 1977–2009.

Source: Sibling histories from DHS surveys.

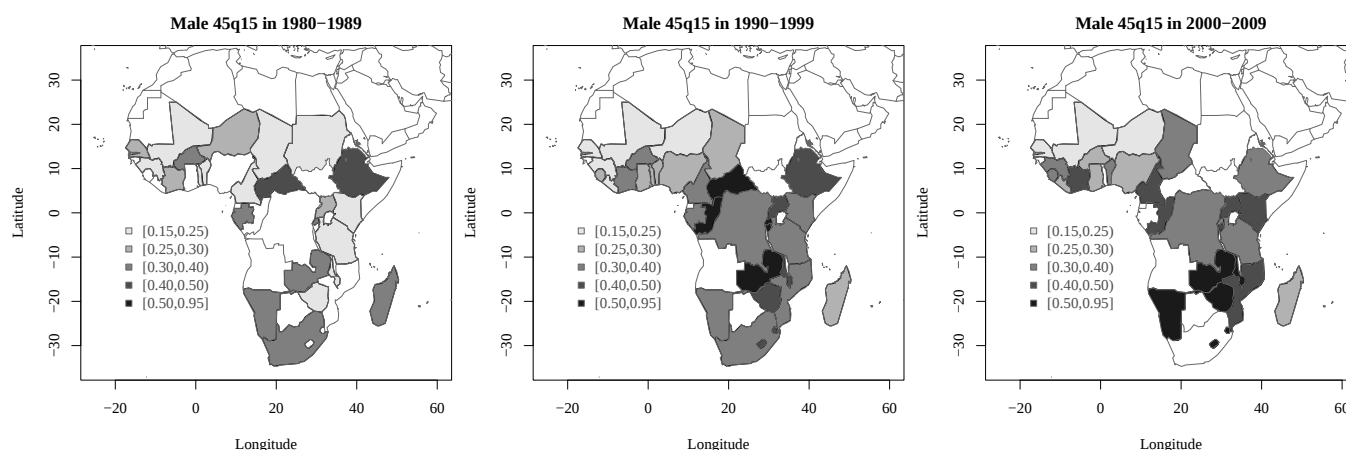


Figure 5 $_{45}q_{15}$ for males, by country; sub-Saharan Africa, 1980-2009.

Note: The values plotted on the maps refer to the average of available estimates for each country during the relevant decade. Source: As for Figure 4.

Most sub-Saharan African countries experienced substantial adult mortality setbacks during the three decades observed. None of the 20 countries with more than one DHS saw a secular decline in their levels of adult mortality. This lack of progress was also reflected by indices summarizing the mortality trends in all the countries for which we had data: the median value of the estimates of $_{45}q_{15}$ for males hovered around 0.25 in the mid-1980s, but had increased to 0.40 by 2000. By 2007 it had declined again to 0.34. These values were two to four times higher than the equivalent figures observed in most West European countries (Rajaratnam et al. 2010c). In Zimbabwe, Swaziland, and Lesotho, values of male

$_{45}q_{15}$ reached extreme levels, surpassing 0.67, a figure which implies that less than a third of 15-year-olds would survive to age 60 if these mortality rates were to persist.

Throughout most of the 1990s increasing regional diversity in adult mortality levels was largely driven by the rates of mortality in East and Southern Africa, which saw steep increases highly suggestive of the massive impact of HIV/AIDS. In several East African countries the mortality rates had been rising since the mid-1980s, and in Kenya, Malawi, and Zambia, $_{45}q_{15}$ doubled over the course of the 1990s. A similar, if somewhat lagged, pattern characterizes Swaziland, Lesotho, Namibia, and Zimbabwe. The geography of the surge in adult mortality rates echoes earlier patterns of HIV incidence. Incidence rates peaked in the early 1990s in East Africa, and in the mid to late 1990s in Southern Africa, before declining. The stabilization of incidence rates is typical of a maturing epidemic, but the declines which followed were probably also the result of three particular developments: changes in sexual behaviour (Gregson et al. 1998; Stoneburner and Low-Beer 2004); the adoption of risk avoidance strategies such as more careful partner selection (Reniers 2008); and, more recently, the expansion of medical interventions including male circumcision and anti-retroviral therapy (ART).

Interestingly, adult mortality rates in East Africa had already peaked before ART was delivered to any significant proportion of the infected population. It is estimated that only 2 per cent of the total population in need of treatment were receiving ART in 2003 in sub-Saharan Africa. ART coverage rates increased to 12 per cent in 2005 and 30 per cent in 2007 (WHO, 2013). Adult mortality between ages 15 and 60 peaked in 2000 in Malawi, in 2001 in Uganda, in 2002 in Zambia, and in 2003 in Namibia and Kenya. Given that there are only a few countries where a DHS was taken after 2007 included in the data we used, our estimates will scarcely reflect the mortality declines that might be expected to follow the widespread availability of ART.

Our estimates suggest that Malawi, Kenya, and Tanzania had some of the lowest adult mortality rates in sub-Saharan Africa in the 1980s. As a direct result of the severe HIV epidemics in East and Southern Africa, however, adult mortality levels in these regions are now among the highest on the continent. The most positive story from East Africa, if not sub-Saharan Africa as a whole, comes from Ethiopia where $_{45}q_{15}$ slowly increased during the early 1990s, but after the figure for men peaked at 0.45, it is estimated that this figure fell by 40 per cent over the next 15 years. Congo, in Central Africa, also appears to have experienced a sustained decline in adult mortality since the mid-1990s, but the level from which the rates began to decline was relatively high and, as is the case for most other Central African countries, the estimates for Congo are based on just one survey and must therefore be considered no more than tentative.

Adult mortality trends in East and Southern Africa are not surprising given the magnitude of the HIV epidemic in these regions. More puzzling is the fact that few, if any, countries in other parts of sub-Saharan Africa registered sustained adult mortality declines in the three decades studied. Although there were modest gains in adult survival in the Sahel in the 1980s, most West and Central African countries experienced either stagnating or increasing mortality levels after 1990. In a few West African countries where mortality increases were most explicit, they can be attributed to AIDS mortality, as in Cameroon and Côte d'Ivoire, or to the consequences, both direct and indirect, of political instability and civil strife as was the case in Liberia, Sierra Leone, and Rwanda. The spike in adult mortality in Rwanda in 1994, clearly visible in Figure 4, was the direct result of civil war and genocide. Trends in the other West and Central African countries are less easily explained without detailed analysis of changes in the causes of death but, unfortunately, the necessary data are scarce. It is almost certain, however, that high, and possibly increasing, mortality rates from non-communicable diseases and external injuries would play a role in any explanation offered for the lack of sustained improvements in adult survival in West

Africa and elsewhere in sub-Saharan Africa (Duthé and Pison 2008; Johnston et al. 2009; Mayosi et al. 2009; Seedat et al. 2009). A recent review highlights considerable heterogeneity in the prevalence of non-communicable diseases (such as cardiovascular diseases, diabetes and cancer), but a common concern is that many of these conditions often go undiagnosed and untreated, resulting in a higher than necessary rate of mortality. Several populations, particularly those in Southern Africa, now face the double, or even triple, burden of high mortality rates from infectious diseases, chronic conditions, and fatal injuries (Dalal et al. 2011).

We note a number of implications for mortality measurement that arise from a comparison of the levels and trends in adult mortality estimated from different sources. First, DHS sibling histories yielded estimates of mortality that were lower than those calculated by UNPD, especially for West African countries which had not experienced severe HIV epidemics (Figure S5). Elsewhere, we have speculated about the possible reasons for this region-specific discrepancy between the two sets of estimates (Reniers et al. 2011). These include a relatively large downward bias in the reporting of mortality in siblings in West Africa compared to East and Southern Africa. Larger family sizes and a higher incidence of polygyny in West Africa could result in disproportionate omissions of siblings. A downward bias in the AIDS mortality estimates calculated by UNPD is another plausible explanation. Second, estimated trends in adult mortality can differ depending on the sources used. This is particularly an issue in those countries that have not been seriously affected by HIV, such as Guinea and Burkina Faso. We believe that because the UNPD derives adult mortality from under-five mortality rates, enforcing the same trend in both indicators, the trends captured by sibling survival histories are more reliable—even although the levels estimated may be too low. We elaborate on this issue in the next section. Finally, our estimates of the mortality of men and women, derived from survival reported in sibling histories, tend to produce larger differences between the sexes than are found in the UNPD estimates. This type of discrepancy is particularly pronounced when considering countries severely affected by HIV. In such cases, and for those countries where we have more than one survey, our estimation approach allowed for the sex differences in mortality to change over time. In Côte d'Ivoire, Kenya, Malawi and Uganda the mortality disadvantage of men appears to increase over time. It is possible that the discrepancies between our estimates and those of UNPD in the differential survival of the sexes point to flaws in the HIV prevalence data from UNAIDS, which are factored into the UNPD estimates. We have previously argued that there is a greater downward bias in the UNAIDS HIV prevalence estimates for men than for women, and the present findings appear to confirm this (Reniers and Eaton 2009).

Overall, our estimates of adult mortality are in line with, though slightly lower than, those developed by the IHME. The fact that the IHME uses additional, complementary data sources, including data on recent household deaths, may serve to inflate their figures above ours.

5. Changes in the relationship between ${}_5q_0$ and ${}_{45}q_{15}$

By applying the estimation methods described above to different, but comparable, data sources, changes in the mortality of adults and children can be analysed side by side. In Figure 6, estimates of ${}_5q_0$ for girls derived from birth histories are plotted against estimates of ${}_{45}q_{15}$ for women obtained from data on the survival of sisters drawn from sibling histories. Estimates are presented for selected countries, for each of which at least there have been two DHSs that collected sibling survival data. To give a sense of the expected relationship between ${}_5q_0$ and ${}_{45}q_{15}$, the light grey squares in the background in Figure 6 plot the relevant points from a series of mortality rates compiled for inclusion in the Human Mortality Database (HMD) (2012). The HMD contains detailed life tables from 37 national territories where death registration and census data are virtually complete. It spans the period from 1751 to 2011, although not all countries are represented throughout the 260 years (on average close to 100 period life tables are

available per country). Populations in the HMD are mostly drawn from Europe and Northern America; few life tables from less developed countries are of sufficient quality to meet the standards required for inclusion in the database. Where figures for sub-Saharan Africa shown in Figure 6 lie outside the cloud of HMD rates this either indicates that the age patterns of mortality in sub-Saharan Africa differ from the historical experience recorded in the HMD—as would be the case in countries where AIDS mortality was high—or points to bias in the mortality indices derived from DHSs. Figure 6 also displays the relationship between ${}_5q_0$ and ${}_{45}q_{15}$ embodied in the West, North, and South models of the Coale-Demeny life table system (Coale et al. 1983). These three models are important for our discussion because the UNPD relies heavily on these and other model schedules of mortality to produce estimates for about 40 African countries with limited data on adult mortality. For the latter populations, the UNPD infers rates of adult mortality from estimates of ${}_5q_0$ and therefore the mortality trends they are able to estimate are constrained by the curve of the model life table ‘family’ they choose to use. For countries severely affected by the HIV epidemic, large deviations from the models can be expected and the UNPD accounts for these in an ad hoc fashion, as explained earlier (United Nations 2011). Figure 6 also indicates that countries without widespread epidemics can sometimes experience declines in child mortality without corresponding declines in adult mortality, as in Senegal, or vice versa, as occurred in Niger pre-1990. Between 1993 and 2004 Guinea simultaneously registered improvements in child survival and increases in adult mortality. These observations underscore the fact that inferences made about adult mortality from estimates of mortality for young children are unsatisfactory and that other methods of estimating adult mortality are sorely needed. A recent innovation was the use by the UNPD of the two-parameter Brass relational logit model to estimate adult mortality for the following seven West African countries: Burkina Faso, Gambia, Mali, Mauritania, Niger, Senegal, and Sierra Leone (United Nations 2011). Mortality measures derived from reports of recent household deaths and sibling survival were used as inputs to estimate the parameters of the Brass model.

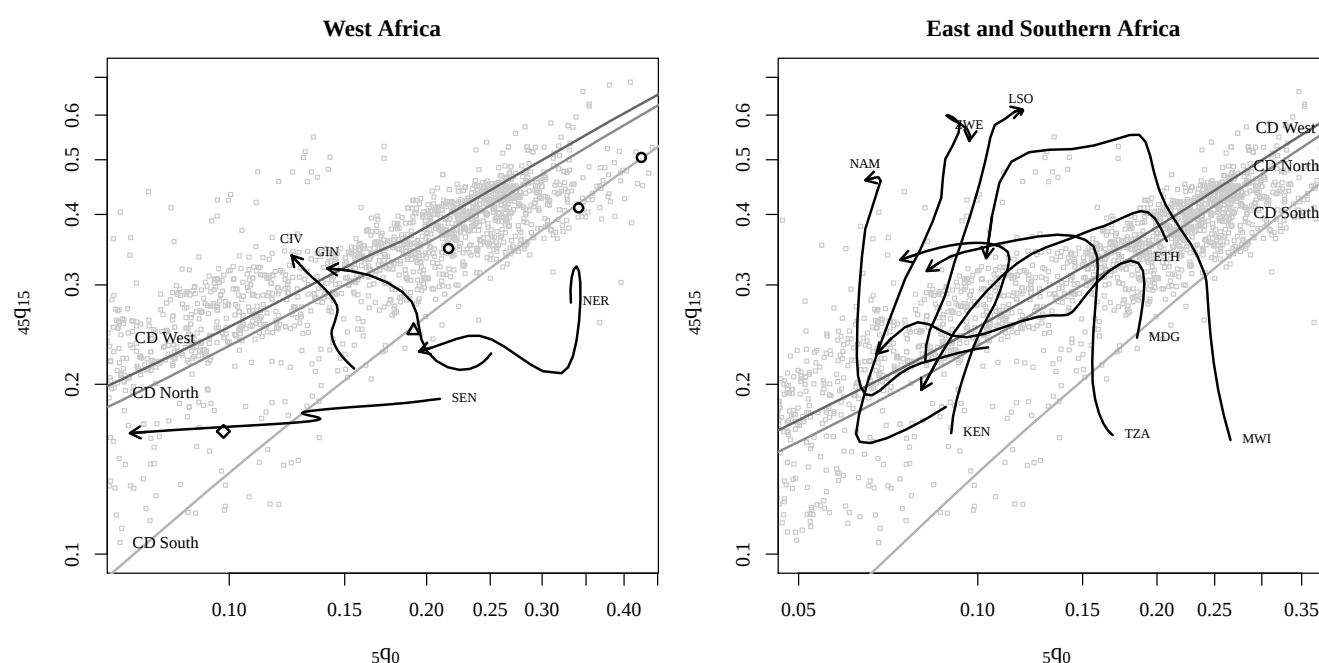


Figure 6 The relationship between ${}_{45}q_{15}$ and ${}_5q_0$ for females as shown by: estimates calculated by the authors from birth and sibling histories for selected sub-Saharan countries (black lines), figures extracted from the Human Mortality Database (grey squares), Coale and Demeny’s South, North, and West model life tables (grey lines), and estimates from the Bandafassi (circles), Mlomp (losange) and Niakhar (triangle) Health and Demographic Surveillance Sites (HDSS) in Senegal.

Note: The sub-Saharan African countries shown are Côte d'Ivoire (CIV), Ethiopia (ETH), Guinea (GIN), Kenya (KEN), Lesotho (LSO), Madagascar (MDG), Malawi (MWI), Namibia (NAM), Niger (NER), Senegal (SEN), United Republic of Tanzania (TZA) and Zimbabwe (ZWE).

Source: As for Figures 2 and 4 for DHS estimates, HMD (2012), and INDEPTH (2004), Pison and Desgrées du Loû (1993), Pison and Langaney (1985) for the Senegalese HDSS.

For most West African countries, DHS estimates of ${}_{45}q_{15}$ at a given a level of ${}_5q_0$ tend to be lower than those in the HMD database. The ratios of adult-to-child mortality in Niger between 1980 and 2004 and in Guinea before 1998 are also considerably lower than those predicted by the Coale-Demeny South model life table. Estimates derived from rural HDSS undertaken in Senegal since the 1970s are also suggestive of higher ratios of adult-to-child mortality. We do not have a clear indication of why the age pattern of mortality in West Africa should depart so much from the historical record documented by the HMD or the HDSS in Senegal, but it is plausible that the low ratios stem from the underestimation of adult mortality from data on siblings; it is unlikely that child mortality rates were overestimated. It is difficult to establish whether the underestimation of adult mortality is limited to surveys conducted in West Africa or whether it affects all DHSs, since most countries in other regions of the continent experienced severe HIV epidemics, and these tend to distort the relationship between adult and child mortality. Even in West Africa, the distortion can be seen in the mortality estimates for Cameroon, between 1986 and 2003, and Côte d'Ivoire, 1982–2004.

The path of adult-to-child mortality ratios shown in Figure 6 differs between three groups of countries in East and Southern Africa. In the first, the data from Ethiopia for the period from 1988 to 2009 and from Madagascar between 1980 and 2007 are in line with the series of HMD rates, and in reasonable agreement with, respectively, the North and West model life tables. In the second, trends for Kenya, Tanzania, and Malawi, as well as Zambia and Uganda (not shown in Figure 6), follow a horseshoe-shaped pattern, where declines in child mortality coincide with increases and then decreases in adult mortality. In the final group, the three Southern African countries show a quite distinct pattern. At first, in both Zimbabwe and Namibia, child mortality declines while adult mortality stagnates. Both countries then experience significant increases in the risks of dying during adulthood while child mortality stagnates in Namibia and increases in Zimbabwe. Rates in Lesotho follow a similar trajectory, although the levels of child mortality are somewhat higher. Probably as a result of the later peak in HIV incidence in Southern African the populations in this region fail to show declines in adult mortality rates similar to those observed in much of East Africa.

6. Discussion

It is evident that sub-Saharan Africa will fall far behind several of the targets of the Millennium Development Goals (MDGs) set in 2000. One of the most prominent MDGs calls for countries to reduce their 1990 under-five mortality rate by 67 per cent by 2015. Despite impressive improvements in child survival in such countries as Madagascar and Liberia, only a few sub-Saharan countries are currently on track to achieve that goal (Bhutta et al. 2010). Their lack of progress is partly explained by the stagnation of child mortality rates during the late 1980s and the 1990s. Evidence from Senegal indicates that setbacks cannot be attributed to the impact of the HIV epidemic alone. Declines in rates of immunization and increases in malaria-related mortality, owing to the emergence of chloroquine-resistant strains of the parasite causing the disease, also played a major role. More encouraging is the recent accelerated decline in under-five mortality in several countries, including Tanzania, Uganda, Kenya, and Senegal. Renewed efforts to increase the distribution of vaccines are undoubtedly amongst the driving forces behind this acceleration, together with the expansion of programmes distributing

bed-nets treated with insecticide (Flaxman et al. 2010), the progress in the provision of vitamin A supplements (UNICEF 2007), and the rapid spread of measures to prevent the transmission of HIV from mothers to their children.

Adult mortality trends in sub-Saharan Africa have followed trajectories that have largely been disconnected from trends in child mortality, at least from the late 1980s onwards. In only a handful of countries, such as Madagascar, Senegal and Ethiopia, have trends in ${}_{45}q_{15}$ even approximately followed the path of the prevailing under-five mortality rates. In other countries adult mortality has either stagnated, sometimes at relatively high levels, as in the Democratic Republic of Congo and Burkina Faso, or has risen dramatically since the 1990s. AIDS mortality dominates many of the all-cause mortality patterns, but the first indications of a decline in adult mortality have emerged in East Africa, in some instances in advance of the large-scale expansion of ART programmes in 2005.

One of the most striking features of the demography of sub-Saharan Africa over the last two decades has been the conjunction of the increasing convergence of national childhood mortality rates with the growing divergence in adult mortality rates. Estimates developed by the United Nations capture the marked heterogeneity of adult mortality rates, but not its full extent. Indeed, estimates of adult mortality from sibling histories are generally lower than UNPD estimates for countries with the lowest adult mortality levels, such as the Sahelian countries, while they tend to be close to, or above, UNPD estimates in countries where mortality rates are highest, mostly in Southern Africa. Other intriguing discrepancies between estimates derived from the various sources relate to differences in adult mortality rates between the sexes. These findings should provide an impetus for the more extensive use of empirical estimates of adult mortality. The UNPD has started to use the two-parameter Brass logit model for some West African countries. Extending this approach to countries affected by HIV/AIDS would be a major step forward. A flexible two-dimensional model has recently been developed from the HMD database, using ${}_5q_0$ and ${}_{45}q_{15}$ as key variables (Wilmoth et al. 2012b). Because it is unclear whether this model can adequately depict mortality profiles in countries with widespread HIV epidemics, one priority area for further research should be to develop a standard schedule of mortality for populations affected by AIDS, as well as a relational model incorporating information on the stage of the epidemic reached by each country.

We should, however, guard against a naïve view that takes survey-based estimates at face value. Our analysis suggests that the underreporting of deaths in sibling histories is pervasive, and much greater than that in birth histories. One limitation of our approach has been the assumption that the pattern of underreporting in data on the survival of children and siblings is constant across surveys. Even though our estimates are useful for examining trends in mortality at the national level, they remain highly dependent on the quality of the data collected by the DHS and should therefore be treated with caution, especially when considering countries where only one set of birth or sibling histories is available, such as the Congo and Sierra Leone. Even when data from successive DHSs can be pooled together to derive estimates of mortality, discrepancies with estimates calculated by the UNPD are sometimes large and the reasons for this demand a thorough assessment.

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Appendix

1. Estimating child mortality

All datasets from the Demographic and Health Surveys (DHS) program were downloaded from www.measuredhs.com (last update: April 2013). The original datasets, with one row for each woman aged 15–49 interviewed, were reformatted into files containing one row for each child recorded. Then, using the reported dates of birth and ages at death, the life course of each child was split into different spells. A new spell was started at each birthday, each time the child survived to see in a new calendar year, and each time the ‘number of completed years preceding the survey’ changed. Figure S1 provides an illustration of the identification of various spells for one child. This example was taken from the DHS conducted in Rwanda in 2010, and refers to a child born in January 2006 who died, just before the survey, at four and a half years of age. All individual spells were then aggregated to form a new dataset in which each row corresponded to a ‘person-period’, that is, a unique combination of a given age, sex, calendar year, and time preceding the survey (TIPS). For each person-period, the total exposure time and number of deaths were computed and weighted by the DHS sample weights designed to ensure representativity. As the fieldwork of a DHS can extend over several months, deaths occurring after the date of the first interview conducted in a particular survey were ignored.

We computed adjustment factors to correct for the under-reporting of deceased children, as documented in the main text. Although not significant, we observed some variation between West and Central Africa and East and Southern Africa, including a slightly greater under-reporting of infant deaths in the first 5 years preceding the survey, before the cut-off date used for the health section in West and Central Africa. Two sets of adjustment factors were specified for (1) West and Central Africa and (2) East and Southern Africa.

A generalized additive model (GAM) was fitted to the data from each country. In GAMs, the independent variable Y_i may follow any exponential distribution. When a Poisson distribution is used, the model is of the form

$$\log(\mu_i) = X_i\theta + \sum f_j(x_{ij}) + \varepsilon_i$$

where $\mu_i \equiv E(Y_i)$, $X_i\theta$ refers to the parametric components of the model, and f_j are smooth functions of covariates x_j (Wood 2006). The advantage of GAMs for our purposes is that no parametric assumption about trends in mortality is required. The only decision to be taken is how to represent the smoothing functions, f_j , including the degree of smoothness required. The latter can be selected as part of the model-fitting process by minimizing the generalized cross-validation score (GCV). The GCV identifies the smoothing parameter that yields the best prediction of each data point as a function of the others when that particular data point is left out of the fit. We used the *mgcv* package in R statistical software, which is freely available through the Comprehensive R Archive Network (CRAN) website (<http://cran.r-project.org/>). To allow for over-dispersion, the scale parameter was estimated rather than fixed, and to avoid over-fitting we inflated the model degrees of freedom in the GCV score by 1.4, as recommended by Wood (2006). Because the GAM smoothed away the excess mortality related to the Rwandan genocide, the period from 1993 to 1995 was removed from the GAM model for Rwanda. Mortality rates and 90 per cent uncertainty intervals for this period in the country’s history were obtained from a simple Poisson regression model including each of the three years as a dummy variable.

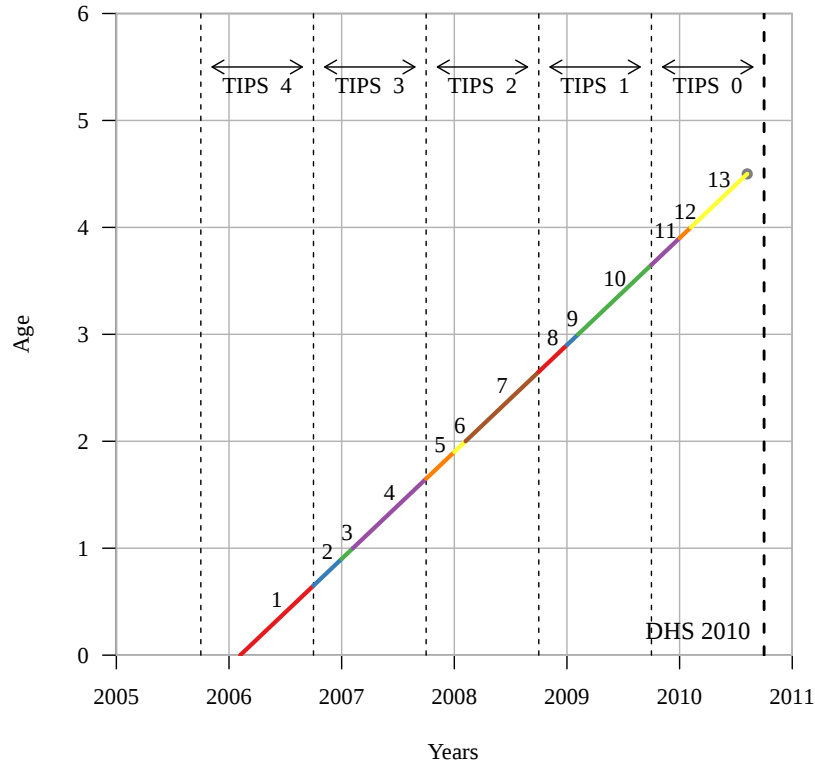


Figure S1 Lexis diagram illustrating how an individual life course is split into different spells to generate ‘person-periods’.

Note: This example was taken from the Demographic and Health Survey conducted in Rwanda in 2010 (DHS 2010), and refers to a child born in January 2006 who died in July 2010, shortly before the survey, at four and a half years of age. This child would contribute 13 different person-periods to our calculations.

TIPS: Time period in completed years since survey

To account for HIV-related bias, we used an approach developed by Walker et al. (2012), in which children are divided into three groups: (i) children born to HIV-negative mothers; (ii) children born to HIV-positive mothers who are themselves infected; and (iii) children who are not infected, despite being born to HIV-positive mothers. The Spectrum population projection software (version 4.45) (Stover et al. 2010) was used to obtain the annual numbers of births for individual countries, the number of HIV-positive women giving birth each year, and the number of HIV-positive infants. The survival time following infection with HIV was estimated through standard patterns, and the background child mortality rates were derived from Coale and Demeny’s West life table. The non-AIDS ${}_5q_0$ was selected from among seven values (0.050, 0.075, 0.100, 0.125, 0.150, 0.200, 0.250), retaining the closest level to the non-AIDS ${}_5q_0$ estimated in the *World Population Prospects* (United Nations 2011). We used a cohort component projection model to estimate the number of births and deaths that went unreported during each of the DHS as a result of the vertical transmission of HIV between mothers and their children. The bias in estimates of under-five mortality was computed for each survey conducted within a country, and an annual series of adjustment factors was obtained by weighting survey-specific adjustments by the number of person-years emanating from the separate surveys.

2. Estimating adult mortality

To estimate adult mortality, DHS datasets were reformatted from files containing one row for each woman aged 15–49 interviewed into files containing one row for each sibling reported, whose life course details were subsequently split into person-period episodes, as outlined above.

To adjust for the under-reporting of deaths, data from all calendar years covered by at least two successive DHSs conducted in a given country were pooled and the age groups and sex of siblings and five-year time periods were interacted with country dummies. For example, if survey A covered the period from 2000 to 2012 and survey B covered the period from 1995 to 2007, person-years referring to the period from 2000 to 2007 were pooled together. The time preceding the survey (TIPS) was included as a set of indicator variables, with one to two exact years before the survey in which an individual's data was collected as the reference period. The exponentiated coefficients on these variables indicate how mortality rates calculated for a point of time well before a survey differ from those obtained using data collected in a survey taken just after the relevant time period. For both sexes, mortality rate ratios drop to less than 85 per cent of the reference-period value when periods more than six years before the survey are considered, apart for the period ten to eleven years before the survey (See lower panel of Figure 1 in main paper, and accompanying text).

Questions about sibling survival were also included in questionnaires administered to men in a sample of households in the course of nine DHSs conducted in sub-Saharan Africa. Our analysis of the decline in the completeness of death reporting is restricted to sibling histories reported by women because Zimbabwe is the only country in which a module asking questions about siblings and their survival status was included in two successive surveys administered to men. Women interviewed by the DHS appear to have been more likely to under-report deaths of their brothers than of their sisters. This could be the result of men's greater mobility and, consequently, less regular contact between the respondent and her brothers. Merdad et al. (2013), however, found no significant differences in mortality estimates and data-quality indicators between sibling histories reported by women and those reported by men. To obtain adult mortality rates, we aggregated the deaths and exposure time reported by female and male respondents when the latter had also been asked about their siblings.

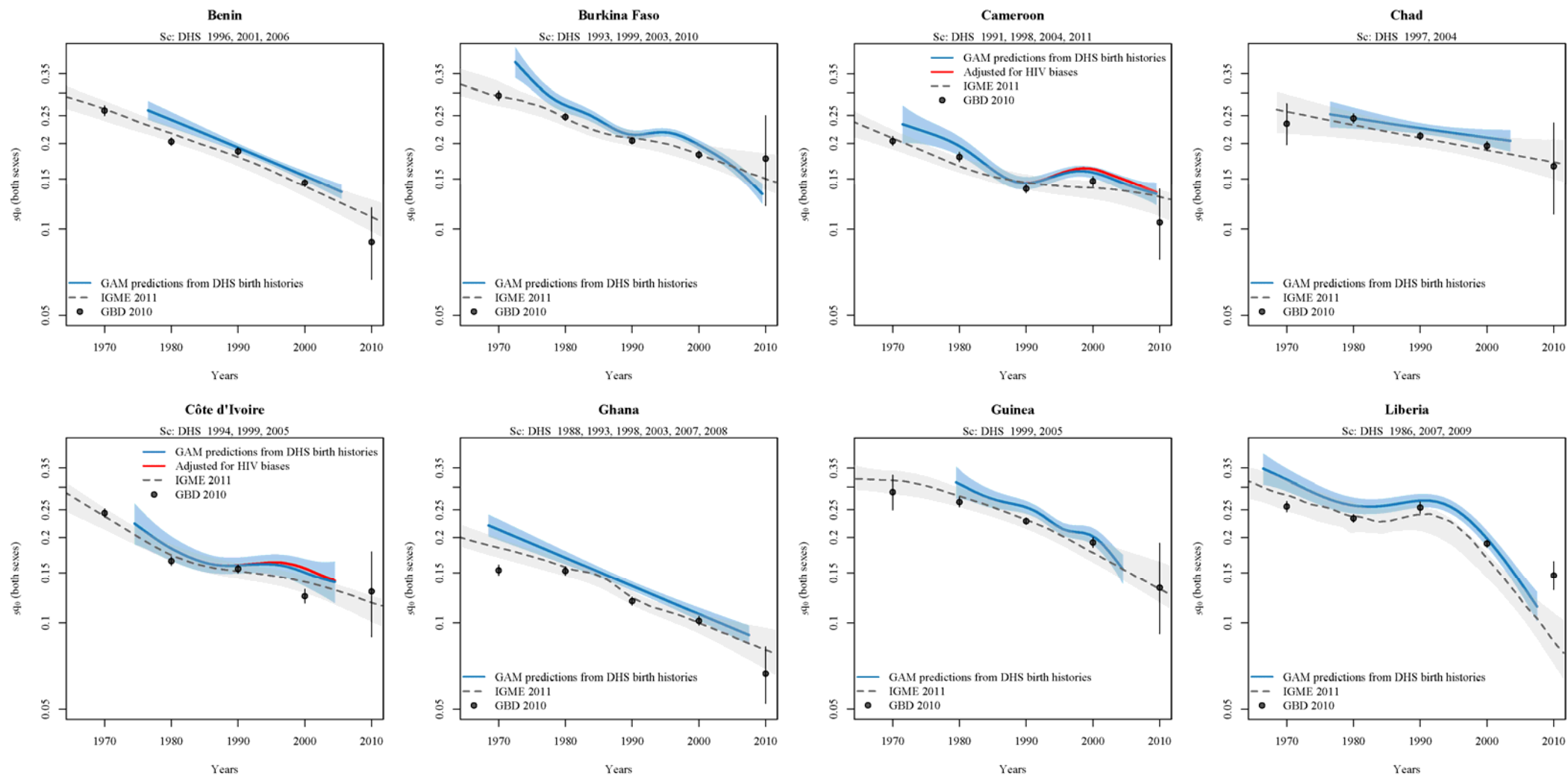
As in the case of child mortality, adjustment factors were applied to the number of deaths reported in all the DHSs, according to the time before the survey at which they had occurred, using the reciprocal of the rate ratios from the Poisson regression. Although not statistically significant, a more rapid decline in the completeness of death reporting was observed in East and Southern Africa, so we again used two sets of correction factors, one for East and Southern Africa and one for West and Central Africa.

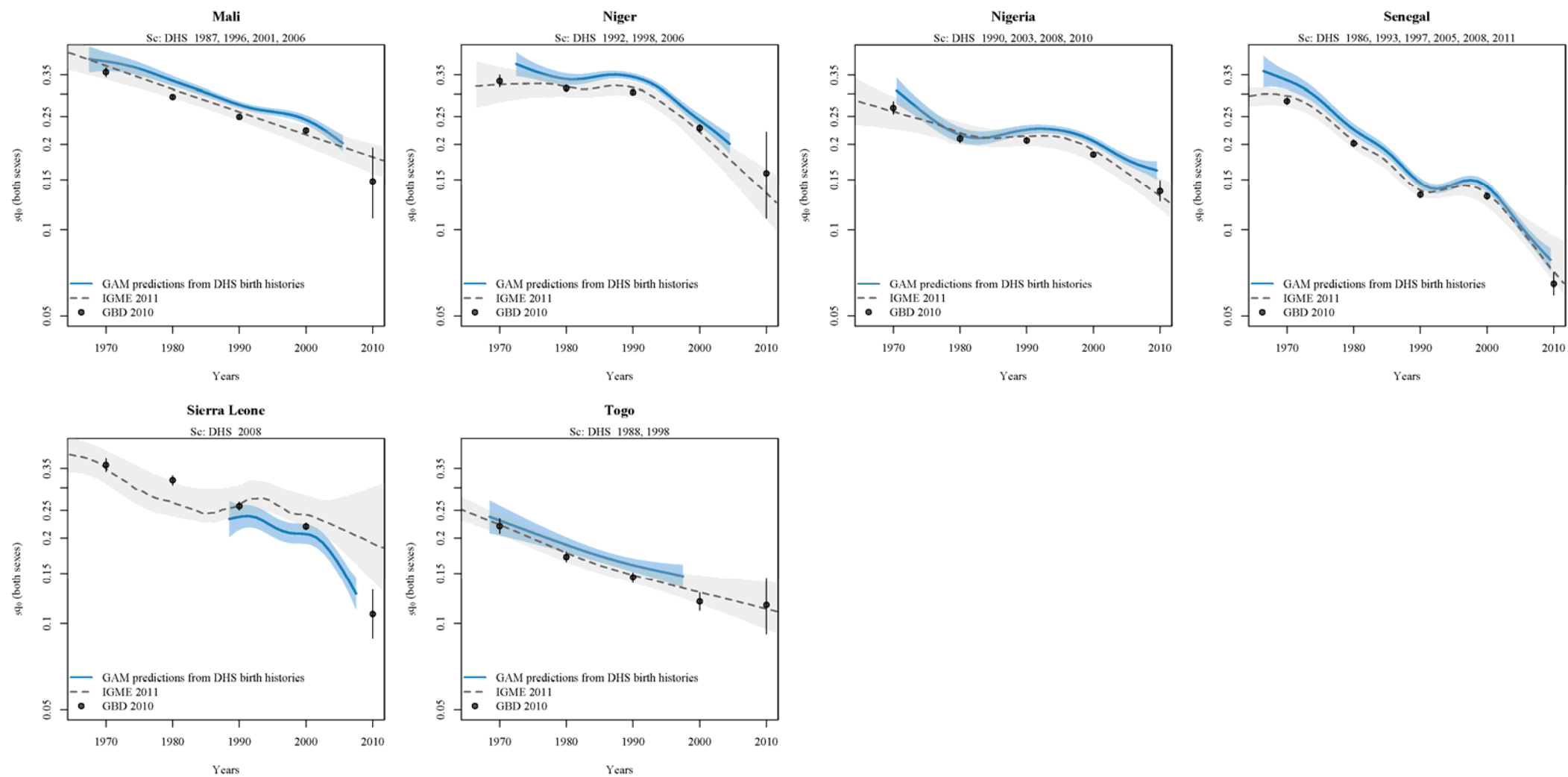
Sibling survival estimates can also be affected by various selection biases. We have discussed these biases and adjustment approaches in greater detail elsewhere (Masquelier 2013). Since no correction method is fully satisfactory, we did not attempt to correct for selection biases, making the critical assumption that mortality is not associated with the size of the sibling group so that any selection biases cancel each other out (Trussell and Rodriguez 1990).

3. Country-specific trends in ${}_5q_0$ in sub-Saharan Africa

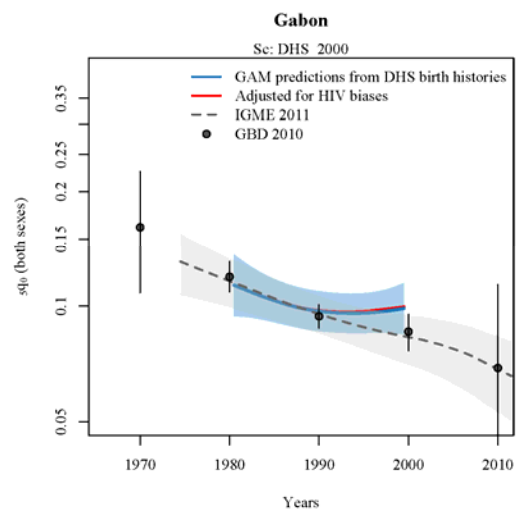
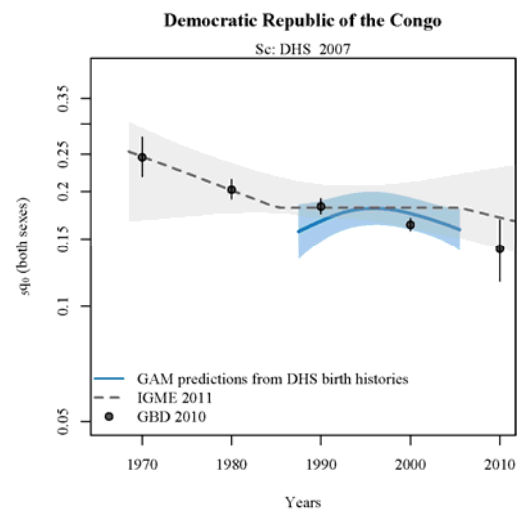
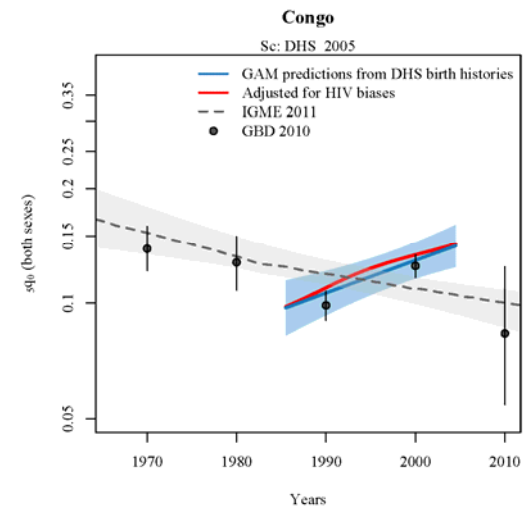
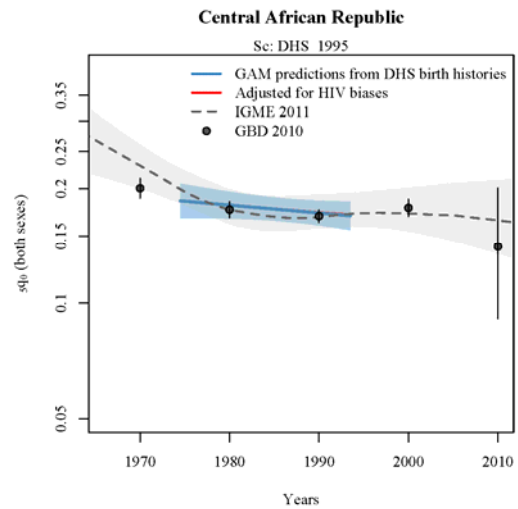
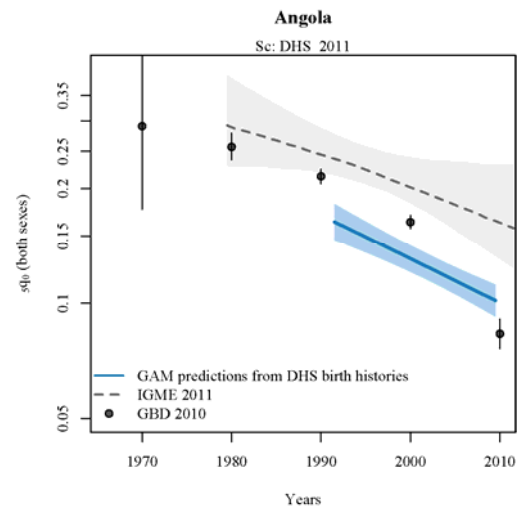
Figure S2 Trends in ${}_5q_0$ for individual countries in sub-Saharan Africa (1966-2009), as estimated from DHS full birth histories (in blue) and adjusted for HIV-related biases (in red), by region.

WEST AFRICA

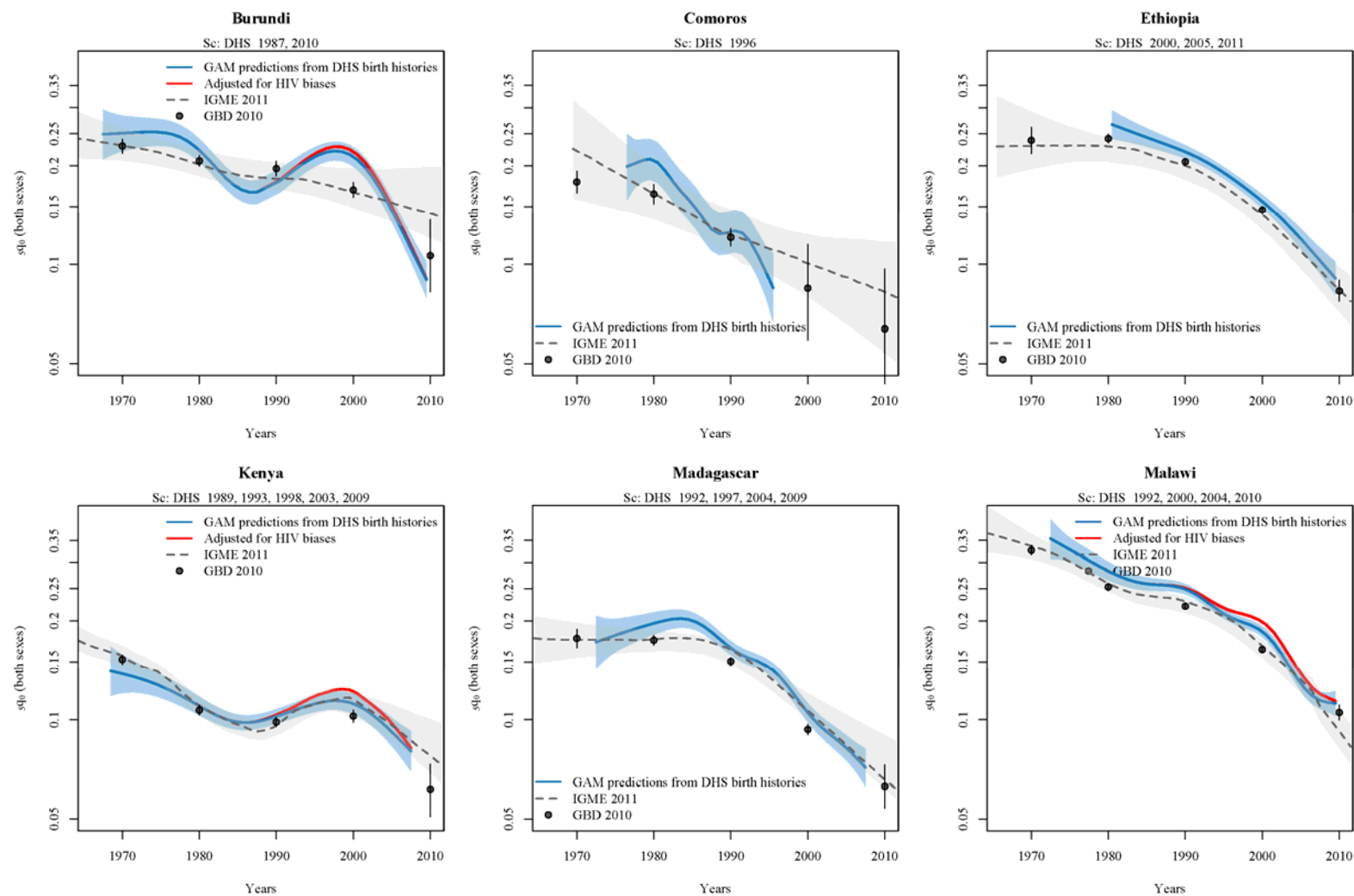


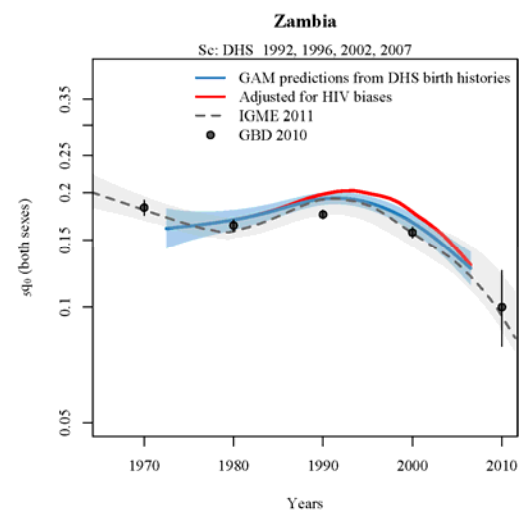
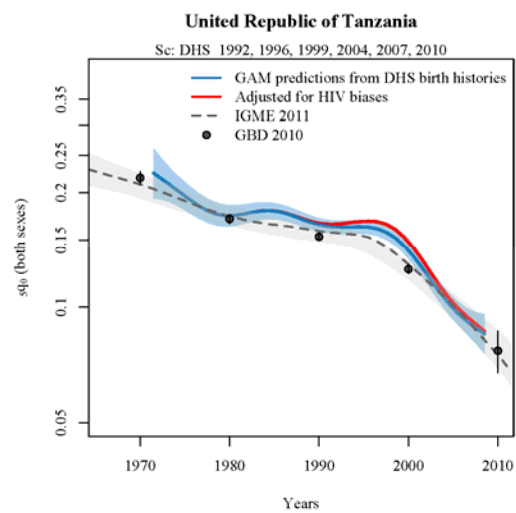
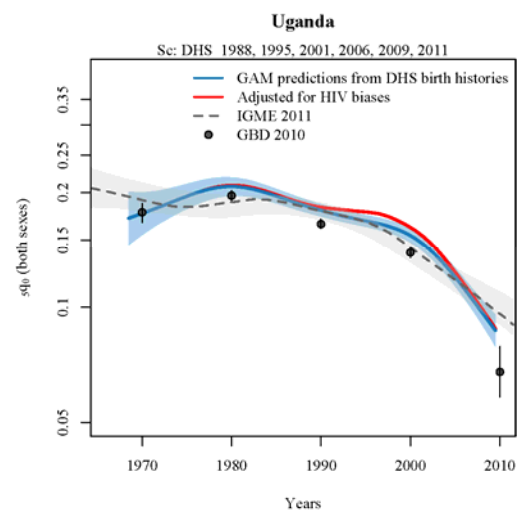
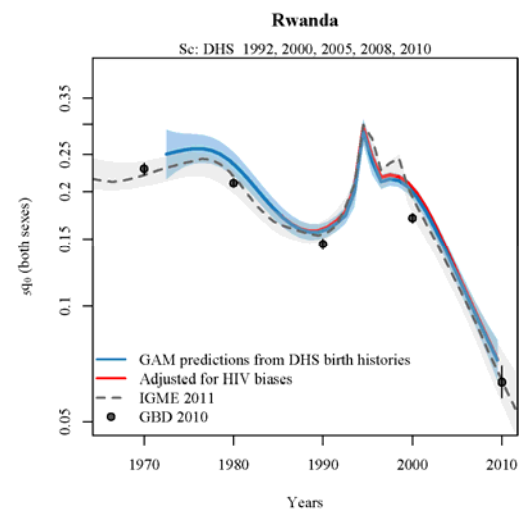
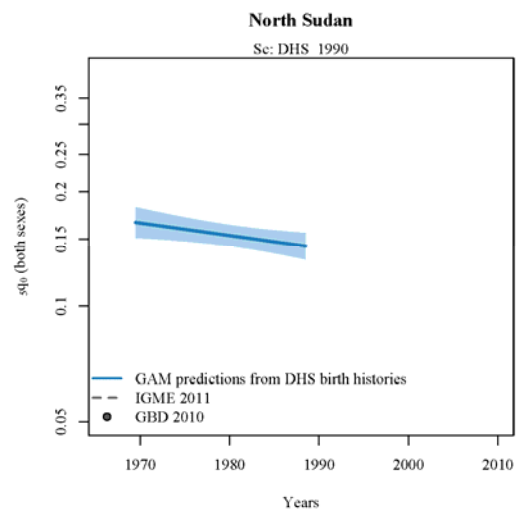
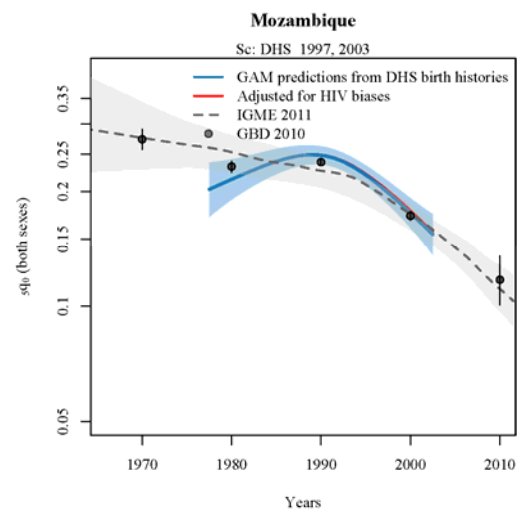


CENTRAL AFRICA

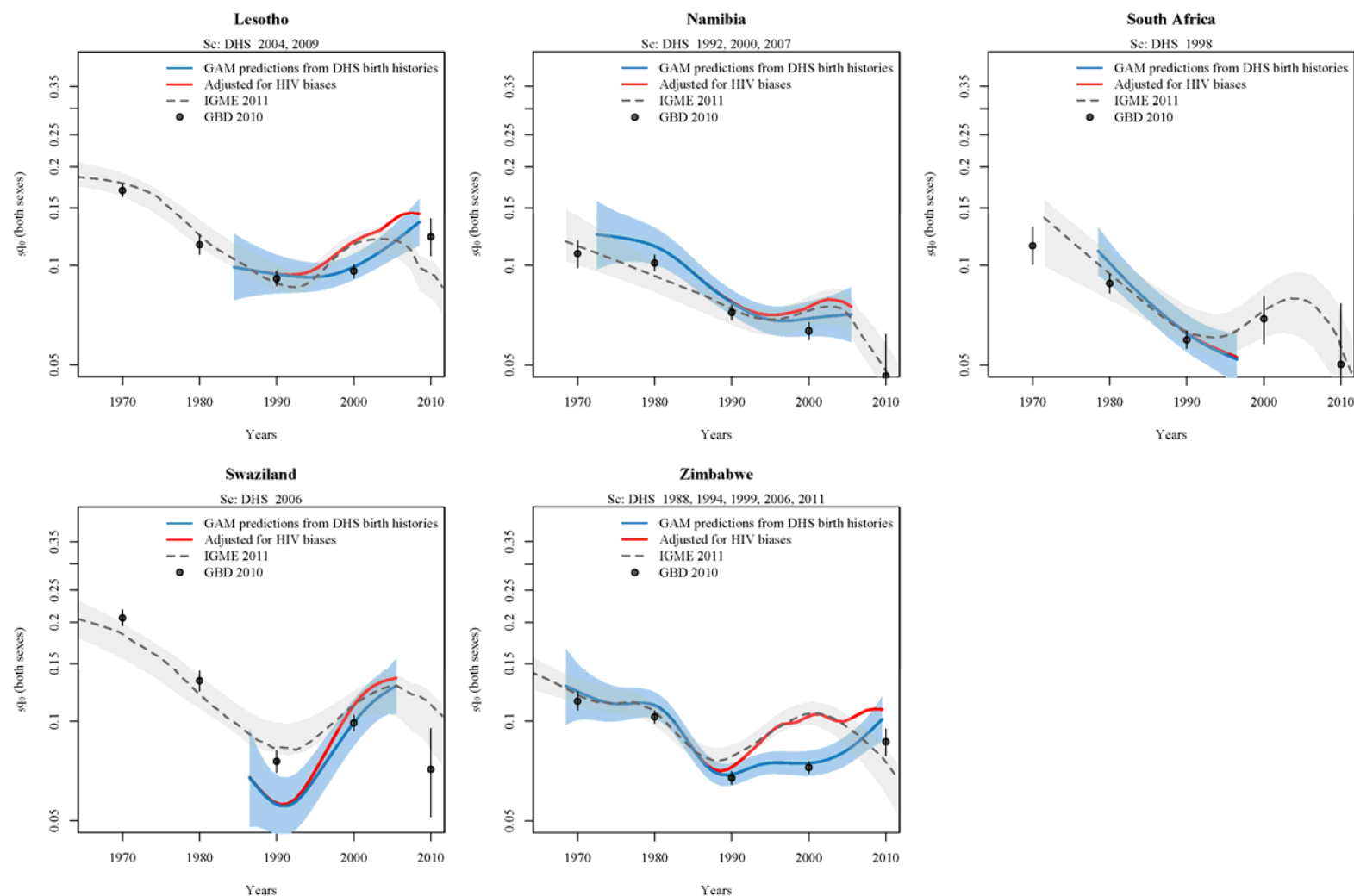


EAST AFRICA





SOUTHERN AFRICA



Notes: 90 per cent uncertainty intervals (UIs) were obtained from coefficients and standard errors of the GAM model and allow for over-dispersion.

The dashed grey lines and shaded areas refer to estimates and 90 per cent UIs from the IGME.

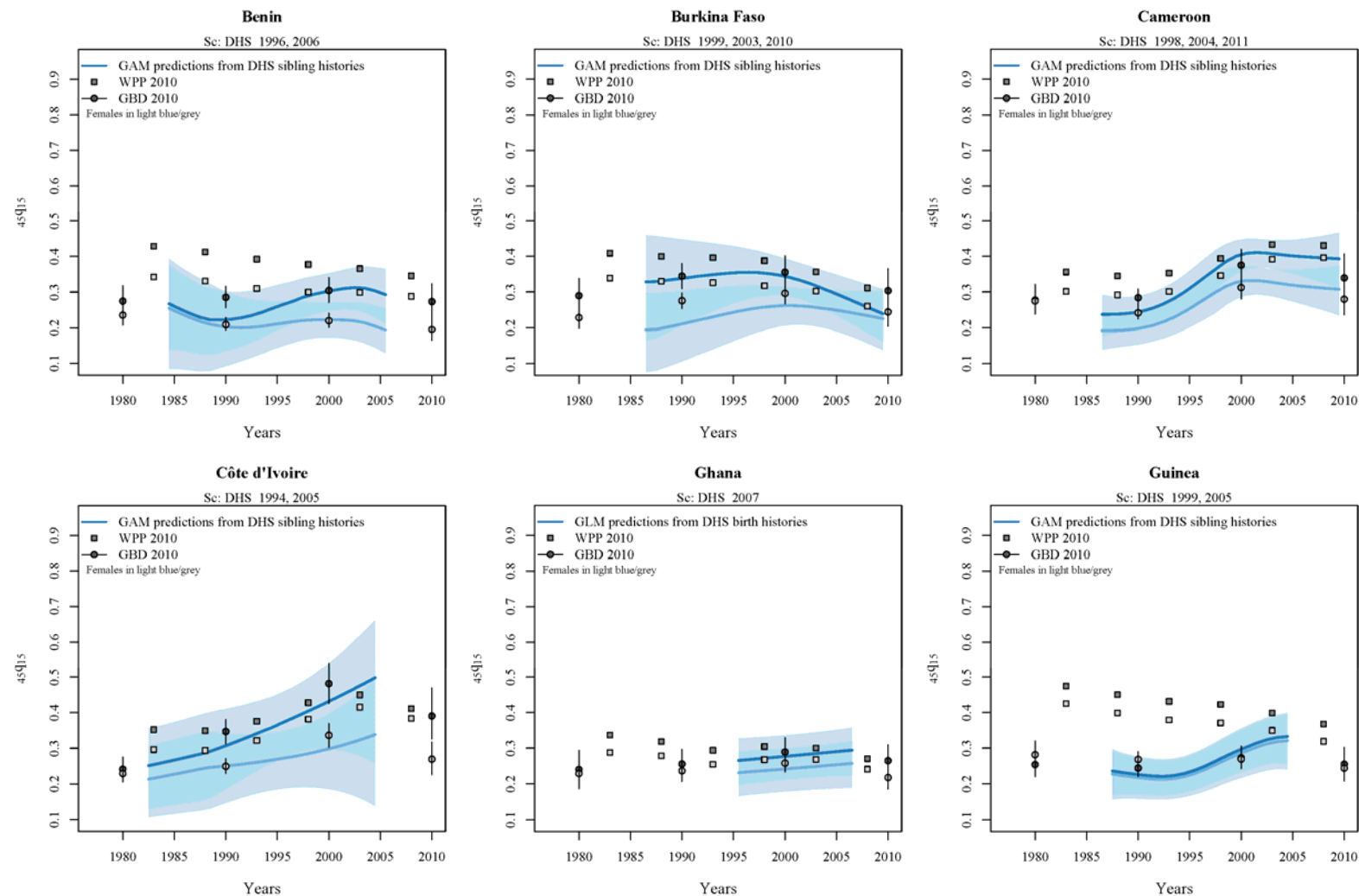
Dots and vertical lines refer to estimates and 95 per cent UIs from the GBD 2010 study.

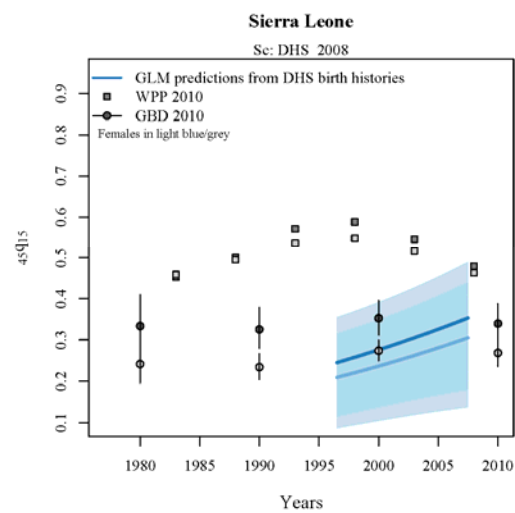
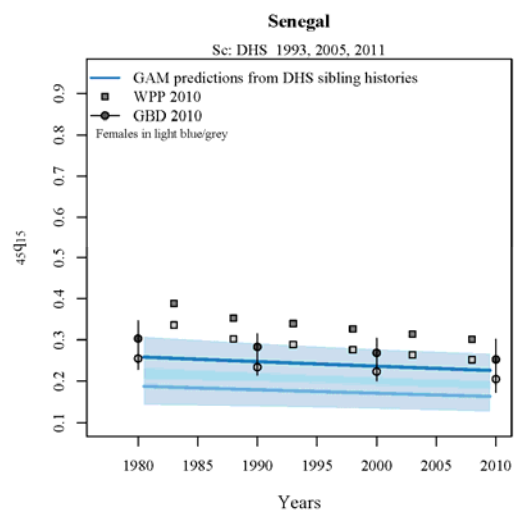
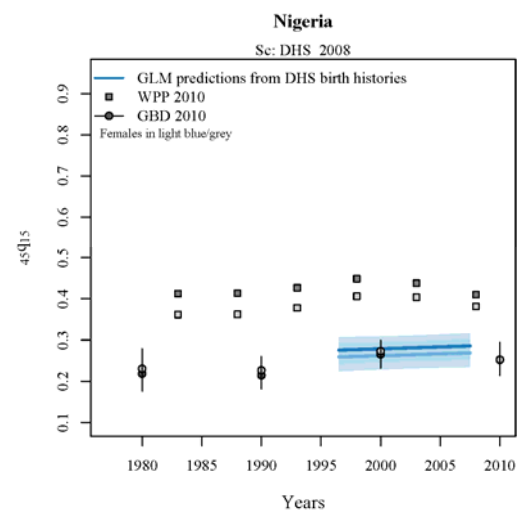
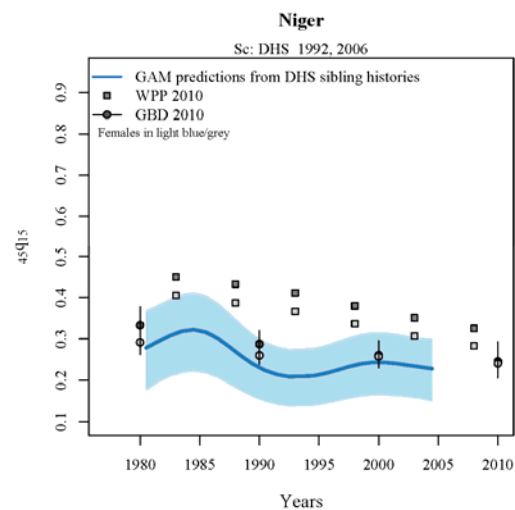
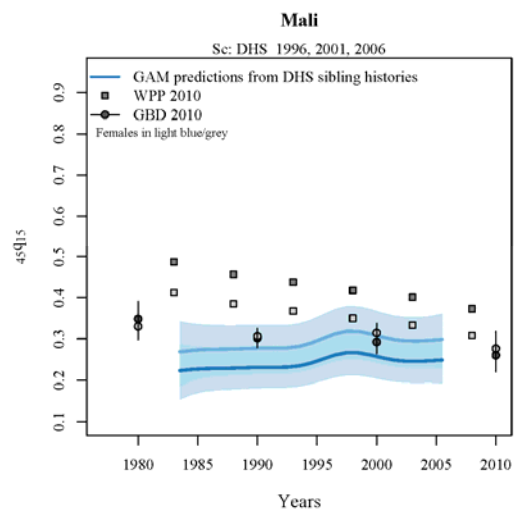
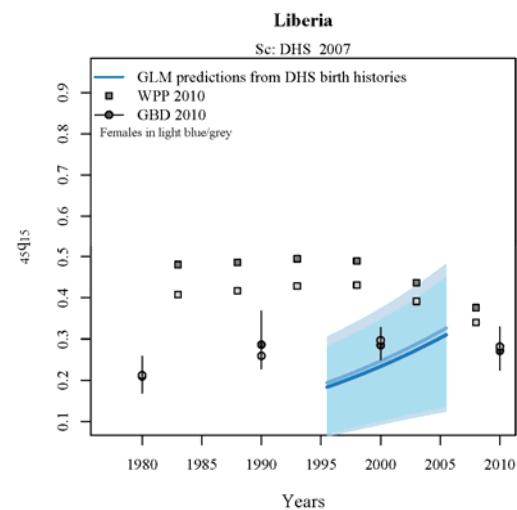
Sources: Our estimates: birth histories from DHS (with adjustment for HIV-related biases); GBD estimates: Wang et al. (2012); IGME estimates: Hill et al. (2012).

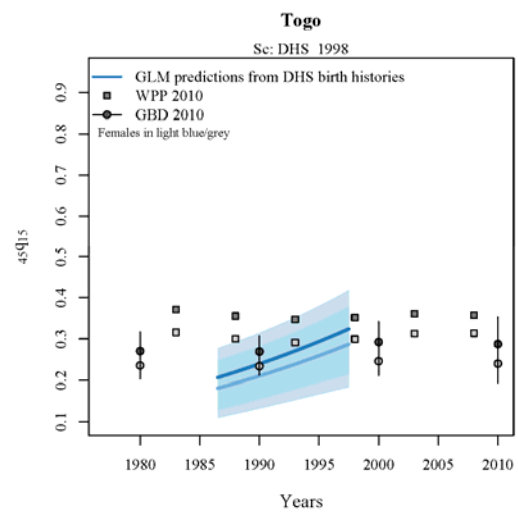
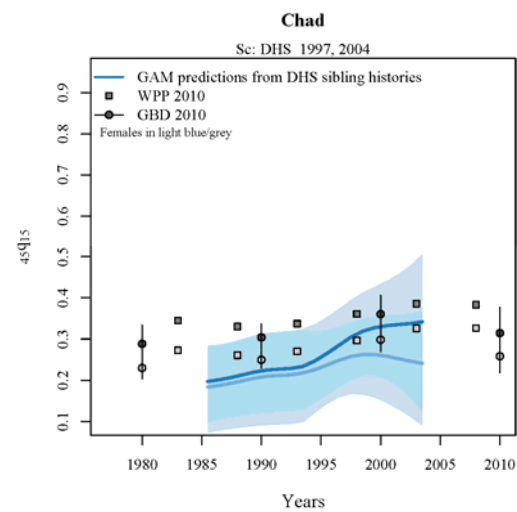
4. Country-specific trends in 45q15 in sub-Saharan Africa

Figure S3 Estimates of $_{45}q_{15}$ (showing 90 per cent uncertainty intervals (UIs)) for individual countries in sub-Saharan Africa (1977-2010), as estimated from DHS sibling histories, by region.

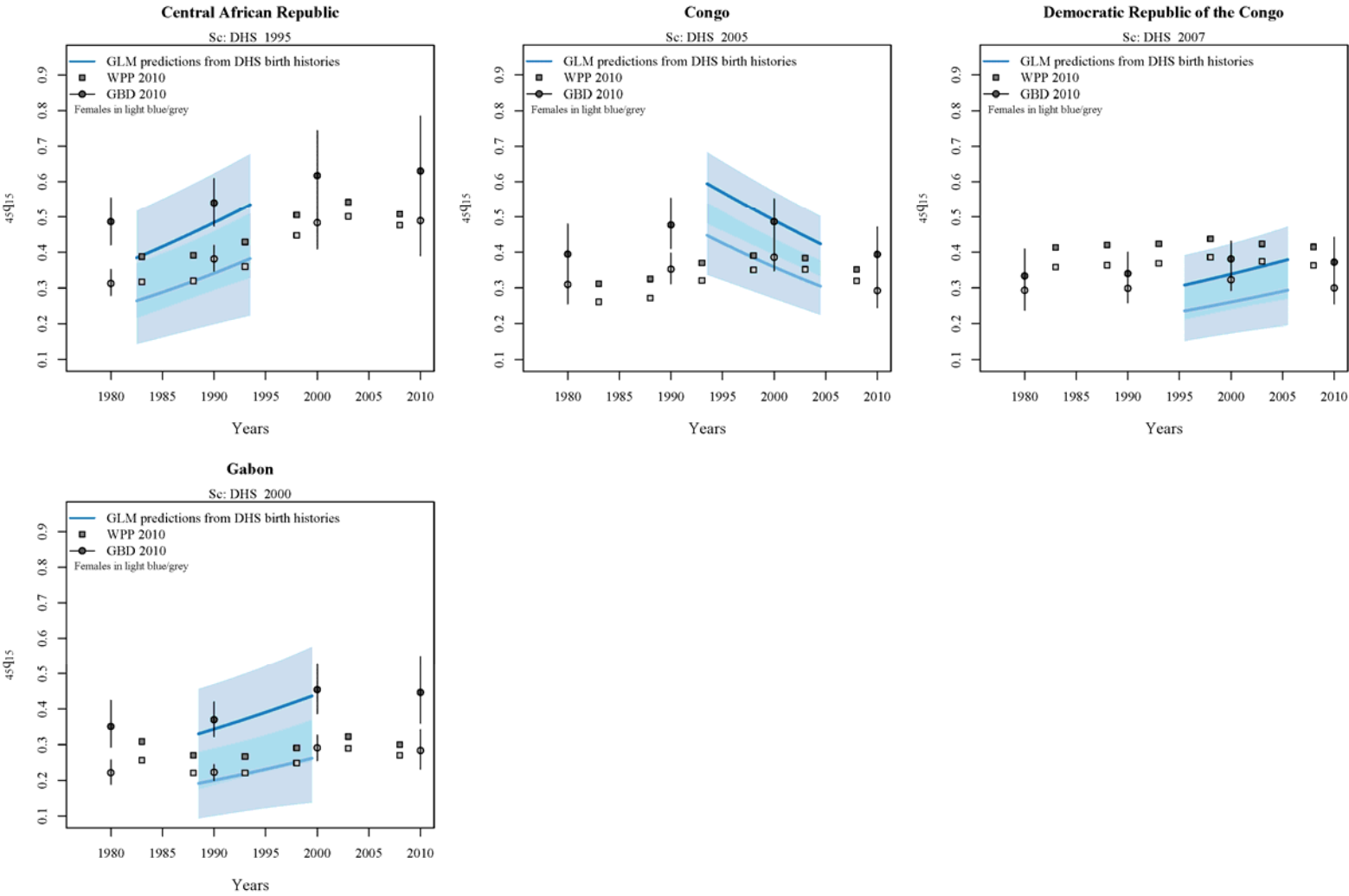
WEST AFRICA



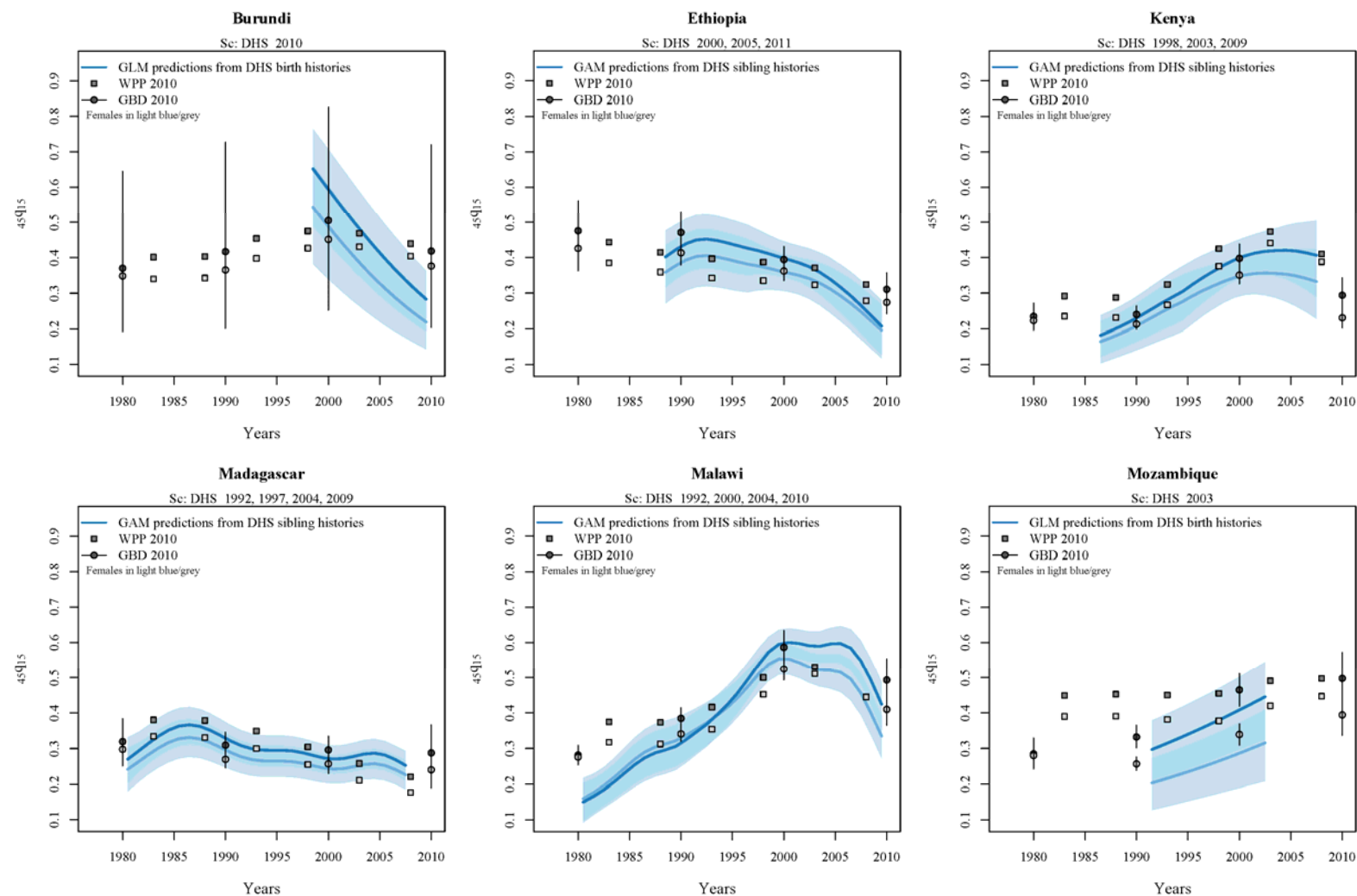


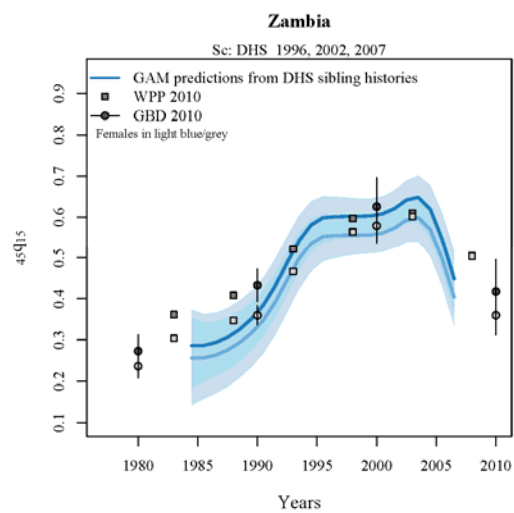
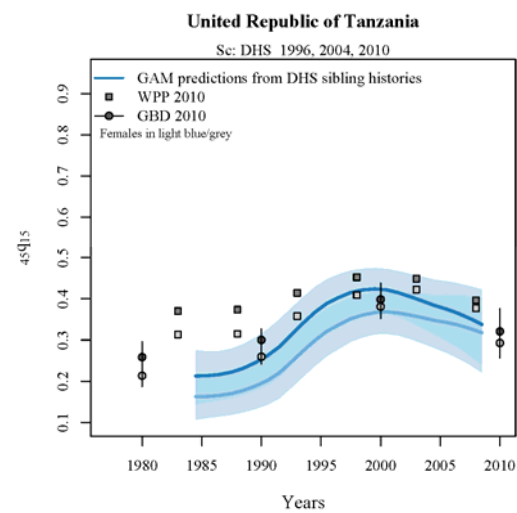
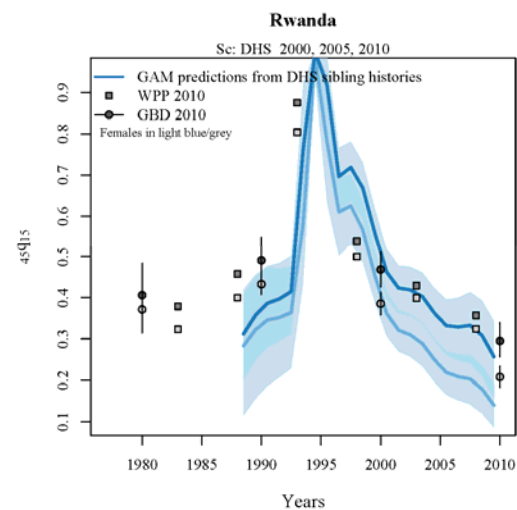
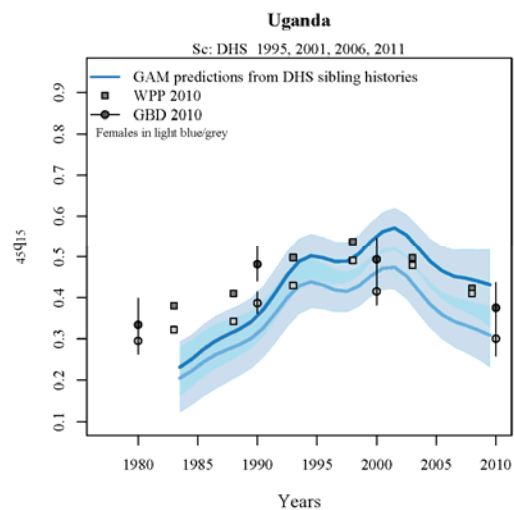
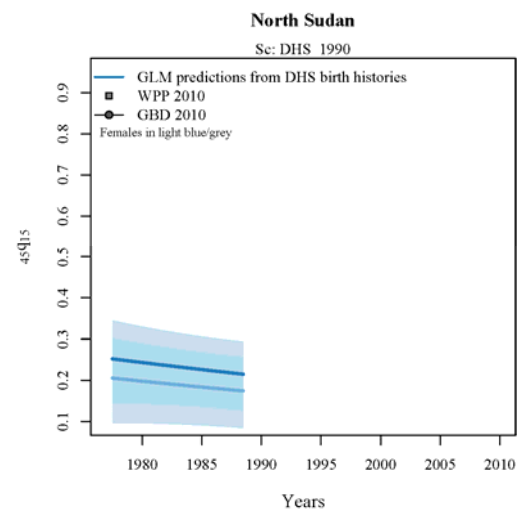


CENTRAL AFRICA

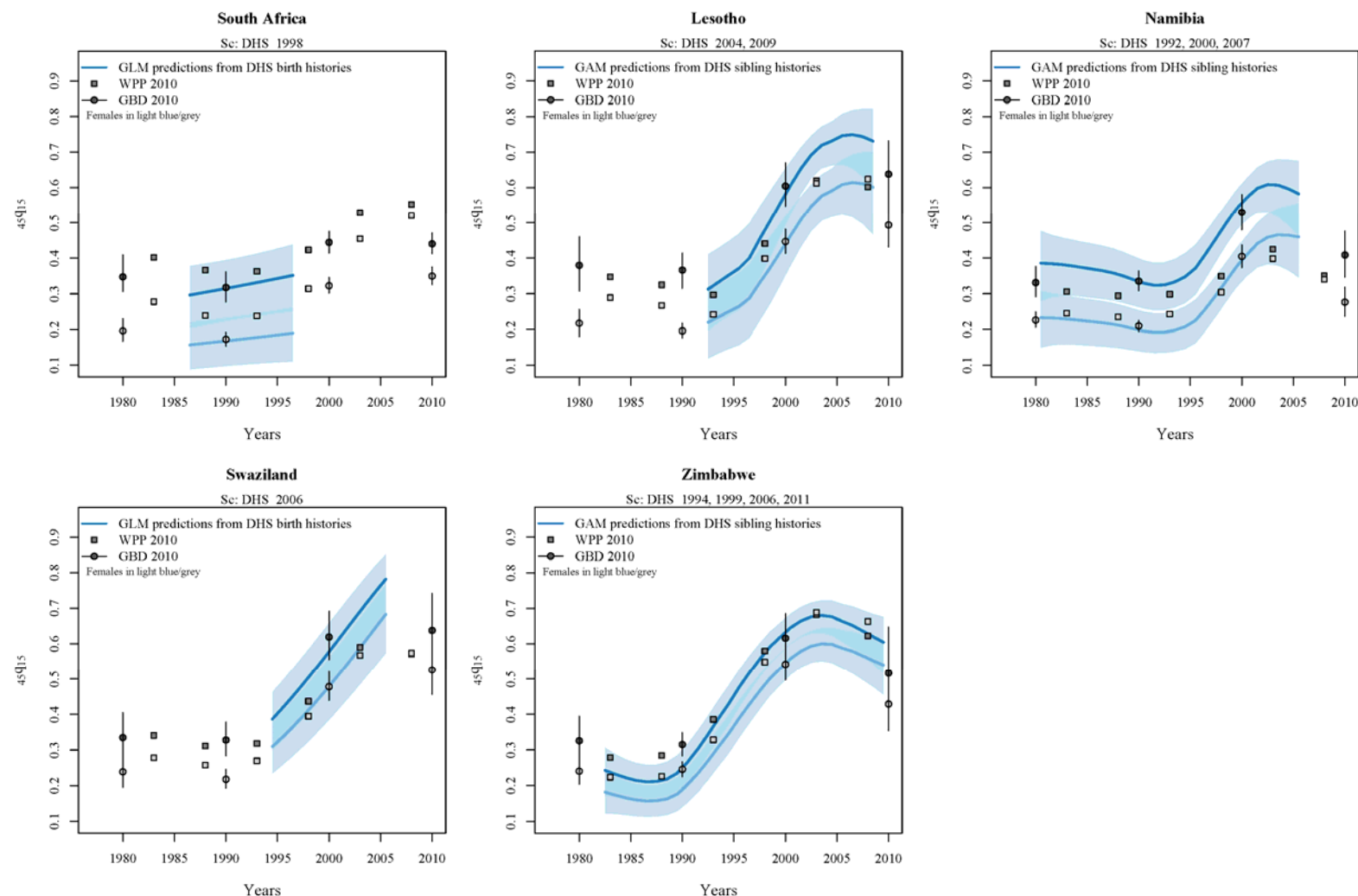


EAST AFRICA





SOUTHERN AFRICA



Note: 90 per cent UIs were obtained from coefficients and standard errors of the GAM model and allow for over-dispersion. For countries with only one DHS with sibling histories, a generalized linear model (GLM) is used, assuming that deaths follow an over-dispersed Poisson distribution.

Squares indicate estimates developed by the Population Division of the United Nations for the 2010 revision of the *World Population Prospects* (WPP)

Dots and vertical lines indicate estimates and 95 per cent UIs from the 2010 Global Burden of Disease (GBD) study.

Source: Our estimates: Sibling histories from DHS; GBD estimates: Wang et al. (2012); *World Population Prospects*: United Nations (2011).

5. Selection of DHS used

We used 107 DHSs conducted in sub-Saharan Africa to estimate trends in ${}_5q_0$, including standard DHSs, Malaria Indicator Surveys (MIS), and AIDS Indicator Surveys (AIS). We omitted the following surveys:

- (1) The DHS conducted in São Tomé and Príncipe in 2008/9, because this country had only 165,000 inhabitants in 2010 and the sample size of 2,615 women aged 15–49 was too small to produce reliable estimates,
- (2) The DHS conducted in Angola in 2007, because the birth histories it collected were truncated, with only births occurring in the six years before the survey being recorded,
- (3) The AIS or MIS taken in Congo in 2009, Mozambique (2009), Senegal (2006), Tanzania (2003), Liberia (2011) and Madagascar (2011), which collected only summary birth histories or recorded just dates of birth and survival status.
- (4) The DHS conducted in Senegal in 1999, because the individual recode was not standardized,
- (5) The DHS conducted in Nigeria in 1999, because the data were known to be of very poor quality (Pullum 2008),
- (6) Eight DHSs which were not available in the public domain: those from Botswana (1988), Cape Verde (2005), Eritrea (1995 and 2002), Guinea (1992), Mauritania (2000/1 and 2003/4), and Uganda (2004/5).

For the estimation of adult mortality, we retained 72 DHSs in which sibling histories were collected in the questionnaires administered to women. We discarded the following data sets:

- (1) The DHS conducted in Nigeria in 1999, because of its poor data quality, and in São Tomé and Príncipe in 2008/9, because of the small sample size,
- (2) The DHS conducted in Mozambique in 1997, because the percentage of deceased siblings with missing or unknown age at death was as high as 24 per cent and the percentage of deceased siblings with unknown or missing information on their date of death was as high as 59 per cent. This indicates that the sibling histories were poorly recorded in the field. They were not analysed in the DHS report on this survey.
- (3) Three DHSs with sibling datasets that were not available in the public domain: Eritrea (1995), Guinea (1992), and Mauritania (2000/1).

Sibling histories were also collected during the World Health Surveys (WHS) implemented by the World Health Organization in 2002–2004 (Üstün et al. 2003). We did not use these because so far, WHS sibling histories have seldom been exploited and little is known about their quality. One study by Obermeyer et al. (2008) used WHSs to estimate mortality caused by violence as a result of war. The authors demonstrated that about 25 per cent of deceased siblings recorded in WHSs had no year of death noted. This is much higher than the average for DHSs, which is about 4.5 per cent. A systematic comparison of mortality estimates derived from DHS and WHS data would provide valuable insights into non-sampling errors in the collection of sibling histories.

6. Classification of regions

The regional classification used in our paper is the one adopted for the 2010 Global Burden of Disease study (GBD) (Wang et al. 2012). Estimates presented for Sudan refer only to North Sudan. The regions, with their constituent countries are listed below. We do not present estimates of child mortality for countries followed by a superscript 1, and no estimates of adult mortality are presented for counties with a superscript 2.

Central Africa: Angola², Central African Republic, Congo, Democratic Republic of the Congo, Equatorial Guinea, Gabon^{1,2}

East Africa: Burundi, Comoros², Djibouti^{1,2}, Eritrea^{1,2}, Ethiopia, Kenya, Madagascar, Malawi, Mauritius^{1,2}, Mozambique, Rwanda, Seychelles^{1,2}, Somalia^{1,2}, (North) Sudan, Uganda, United Republic of Tanzania, Zambia

Southern Africa: Botswana, Lesotho, Namibia, South Africa, Swaziland, Zimbabwe

West Africa: Benin, Burkina Faso, Cameroon, Cape Verde^{1,2}, Chad, Côte d'Ivoire, Gambia^{1,2}, Ghana, Guinea, Guinea-Bissau^{1,2}, Liberia, Mali, Mauritania^{1,2}, Niger, Nigeria, São Tomé and Príncipe^{1,2}, Senegal, Sierra Leone, Togo

7. Additional tables

Table S1 provides estimates of ${}_5q_0$, after adjustment for HIV-related biases, by country and sex for successive five-year periods between 1975 and 2005. Table S2 provides estimates of ${}_{45}q_{15}$ by country and sex for successive five-year periods between 1980 and 2005. Table S3 provides some indication of the quality of the fit of the Generalized Additive Models (GAM), used for child mortality and for adult mortality when at least two datasets are available per country, and General Linear Models (GLM), used for adult mortality when only one DHS has included the module on sibling survival. In the latter table the 'Disp' column provides the dispersion parameters, the 'Deviance explained' column indicates the proportion of the total deviance explained by the GAM or GLM models fitted, and the 'Prop. in 90% UIs' column lists the proportion of annual raw values falling within the 90 per cent confidence intervals of the predictions. Because annual raw values vary quite considerably, a relatively small percentage of data points fall within the confidence intervals estimated from the model (just 63 per cent of the annual raw ${}_5q_0$ and 64 per cent of estimates of ${}_{45}q_{15}$).

Table S1: Trends in ${}_5q_0$ by country and sex, sub-Saharan Africa (1975-2005)

	Females							Males						
	1975	1980	1985	1990	1995	2000	2005	1975	1980	1985	1990	1995	2000	2005
Angola					0.14	0.12	0.11					0.15	0.13	0.11
Benin		0.22	0.20	0.18	0.16	0.15	0.13		0.25	0.22	0.19	0.17	0.15	0.13
Burkina Faso	0.31	0.26	0.23	0.20	0.21	0.19	0.16	0.33	0.27	0.24	0.22	0.22	0.20	0.16
Burundi	0.25	0.21	0.16	0.17	0.21	0.2	0.13	0.25	0.22	0.17	0.19	0.23	0.22	0.15
Cameroon	0.20	0.18	0.15	0.13	0.15	0.15	0.14	0.22	0.20	0.16	0.15	0.16	0.17	0.15
CAR	0.17	0.17	0.17	0.16				0.19	0.18	0.18	0.18			
Chad		0.23	0.22	0.21	0.20	0.20			0.25	0.24	0.23	0.22	0.21	
Comoros		0.19	0.14	0.12	0.08				0.21	0.15	0.13	0.09		
Congo			0.09	0.10	0.11	0.12				0.10	0.12	0.13	0.14	
Côte d'Ivoire	0.20	0.16	0.15	0.14	0.15	0.14		0.22	0.19	0.17	0.17	0.17	0.16	
DR Congo				0.16	0.17	0.16	0.15				0.18	0.19	0.18	0.17
Ethiopia		0.25	0.22	0.20	0.17	0.14	0.10		0.28	0.25	0.23	0.20	0.16	0.12
Gabon		0.10	0.09	0.09	0.09				0.12	0.11	0.10	0.10		
Ghana	0.18	0.16	0.14	0.12	0.11	0.10	0.09	0.19	0.17	0.15	0.14	0.12	0.11	0.10
Guinea		0.29	0.26	0.24	0.20	0.18			0.30	0.27	0.26	0.22	0.20	
Kenya	0.12	0.10	0.09	0.10	0.11	0.11	0.09	0.13	0.11	0.10	0.11	0.12	0.13	0.10
Lesotho			0.09	0.08	0.09	0.10	0.12			0.10	0.10	0.11	0.13	0.16
Liberia	0.26	0.24	0.24	0.25	0.23	0.18	0.13	0.29	0.27	0.27	0.28	0.25	0.20	0.14
Madagascar	0.17	0.19	0.19	0.15	0.13	0.10	0.08	0.19	0.20	0.20	0.17	0.14	0.10	0.08
Malawi	0.31	0.27	0.24	0.23	0.20	0.18	0.12	0.32	0.28	0.26	0.25	0.22	0.20	0.14
Mali	0.35	0.32	0.29	0.26	0.24	0.23	0.19	0.36	0.33	0.30	0.28	0.26	0.25	0.21
Mozambique		0.20	0.23	0.23	0.21	0.17			0.23	0.25	0.25	0.22	0.17	
Namibia	0.11	0.10	0.08	0.07	0.06	0.07	0.06	0.12	0.12	0.10	0.08	0.08	0.08	0.08
Niger	0.35	0.33	0.34	0.33	0.29	0.23		0.35	0.33	0.34	0.34	0.29	0.24	
Nigeria	0.23	0.2	0.2	0.21	0.21	0.19	0.17	0.26	0.22	0.22	0.23	0.23	0.21	0.18
North Sudan	0.15	0.14	0.14					0.16	0.16	0.15				
Rwanda	0.24	0.22	0.16	0.15	0.23	0.18	0.11	0.27	0.24	0.18	0.17	0.25	0.20	0.12
Senegal	0.27	0.21	0.17	0.13	0.13	0.13	0.09	0.28	0.22	0.19	0.15	0.15	0.14	0.10
Sierra Leone				0.22	0.20	0.19	0.14				0.24	0.22	0.21	0.16
South Africa		0.08	0.06	0.05	0.05				0.11	0.08	0.07	0.06		
Swaziland				0.05	0.07	0.11	0.13				0.06	0.08	0.12	0.14
Togo	0.20	0.18	0.16	0.15	0.14			0.21	0.19	0.18	0.17	0.16		
Uganda	0.18	0.19	0.18	0.17	0.16	0.14	0.11	0.20	0.22	0.20	0.19	0.19	0.17	0.13
UR Tanzania	0.18	0.16	0.17	0.16	0.16	0.14	0.09	0.20	0.18	0.18	0.17	0.17	0.15	0.10
Zambia	0.16	0.16	0.17	0.19	0.18	0.16	0.12	0.16	0.17	0.18	0.20	0.21	0.18	0.15
Zimbabwe	0.10	0.10	0.07	0.07	0.08	0.09	0.09	0.12	0.12	0.08	0.08	0.10	0.11	0.11

Source: Birth histories from DHS surveys (with adjustment for HIV-related biases).

Table S2: Trends in $_{45q15}$ by country and sex, sub-Saharan Africa (1975-2005)

	Females						Males					
	1980	1985	1990	1995	2000	2005	1980	1985	1990	1995	2000	2005
Benin		0.24	0.20	0.21	0.22	0.19		0.25	0.22	0.26	0.31	0.29
Burkina Faso			0.21	0.25	0.26	0.25			0.34	0.35	0.34	0.29
Burundi					0.47	0.31					0.57	0.40
Cameroon			0.20	0.26	0.33	0.32			0.25	0.32	0.41	0.40
CAR		0.29	0.35					0.42	0.49			
Chad		0.18	0.21	0.24	0.26			0.20	0.22	0.27	0.33	
Congo				0.42	0.35					0.56	0.48	
Côte d'Ivoire		0.23	0.25	0.27	0.30			0.27	0.31	0.37	0.44	
DR Congo				0.23	0.26	0.29				0.31	0.34	0.38
Ethiopia			0.39	0.39	0.36	0.29			0.44	0.43	0.39	0.32
Gabon			0.20	0.23					0.35	0.40		
Ghana				0.23	0.24	0.25				0.27	0.28	0.29
Guinea			0.22	0.23	0.29				0.22	0.24	0.30	
Kenya			0.22	0.29	0.35	0.35			0.24	0.33	0.40	0.42
Lesotho				0.26	0.46	0.61				0.37	0.61	0.75
Liberia				0.19	0.25	0.33				0.18	0.24	0.31
Madagascar	0.24	0.33	0.29	0.26	0.24	0.25	0.27	0.36	0.32	0.30	0.27	0.28
Malawi	0.16	0.27	0.34	0.44	0.55	0.52	0.15	0.25	0.32	0.46	0.6	0.60
Mali		0.27	0.28	0.30	0.30	0.30		0.23	0.23	0.25	0.25	0.25
Mozambique				0.24	0.29					0.35	0.42	
Namibia	0.23	0.22	0.20	0.22	0.41	0.46	0.39	0.37	0.33	0.37	0.57	0.58
Niger	0.28	0.32	0.22	0.22	0.24		0.28	0.32	0.22	0.22	0.24	
Nigeria					0.26	0.27					0.28	0.28
North Sudan	0.20	0.18					0.24	0.22				
Rwanda			0.35	0.78	0.36	0.22			0.39	0.92	0.46	0.33
Senegal	0.19	0.18	0.18	0.18	0.17	0.17	0.26	0.25	0.25	0.24	0.24	0.23
Sierra Leone					0.24	0.29					0.28	0.33
South Africa			0.17	0.19					0.32	0.35		
Swaziland				0.34	0.50	0.68				0.42	0.60	0.78
Togo			0.21	0.26					0.24	0.30		
Uganda		0.24	0.33	0.43	0.47	0.36		0.27	0.37	0.50	0.56	0.47
UR Tanzania		0.16	0.20	0.32	0.37	0.34		0.21	0.26	0.39	0.42	0.38
Zambia		0.26	0.35	0.55	0.56	0.50		0.29	0.38	0.60	0.61	0.55
Zimbabwe		0.16	0.20	0.39	0.56	0.59		0.21	0.27	0.48	0.65	0.66

Source: Sibling histories from DHS surveys.

Table S3: Summary of GAM and GLM fits

Country	Child mortality			Type	Adult mortality		
	Disp.	Deviance explained	Prop. in 90% UIs		Disp.	Deviance explained	Prop. in 90% UIs (males)
Angola	1.33	0.93	0.42	-	-	-	-
Benin	1.18	0.94	0.60	GAM	1.18	0.42	0.68
Burkina Faso	1.59	0.92	0.66	GAM	1.46	0.40	0.62
Burundi	1.49	0.89	0.56	GLM	1.60	0.40	0.67
Cameroon	1.41	0.91	0.59	GAM	1.24	0.54	0.67
CAR	1.27	0.91	0.50	GLM	1.40	0.35	0.42
Chad	1.66	0.90	0.64	GAM	1.31	0.18	0.89
Comoros	1.16	0.88	0.75	-	-	-	-
Congo	1.88	0.83	0.35	GLM	1.98	0.33	0.58
Côte d'Ivoire	2.09	0.85	0.48	GAM	1.77	0.33	0.70
DR Congo	3.13	0.92	0.47	GLM	1.93	0.39	0.73
Ethiopia	2.81	0.93	0.60	GAM	2.77	0.34	0.77
Gabon	1.51	0.84	0.70	GLM	1.59	0.35	0.50
Ghana	1.30	0.84	0.50	GLM	1.43	0.48	0.58
Guinea	1.50	0.92	0.73	GAM	1.20	0.26	0.44
Kenya	1.61	0.89	0.70	GAM	1.82	0.49	0.68
Lesotho	1.49	0.89	0.72	GAM	1.83	0.69	0.82
Liberia	1.87	0.91	0.71	GLM	3.18	0.22	0.91
Madagascar	1.90	0.90	0.56	GAM	1.87	0.29	0.57
Malawi	1.74	0.95	0.74	GAM	1.96	0.65	0.57
Mali	1.84	0.94	0.67	GAM	1.71	0.28	0.52
Mozambique	3.06	0.93	0.81	GLM	1.78	0.37	0.50
Namibia	1.59	0.82	0.76	GAM	1.71	0.60	0.73
Niger	1.73	0.91	0.61	GAM	1.50	0.19	0.54
Nigeria	1.87	0.91	0.72	GLM	1.68	0.49	0.17
North Sudan	1.35	0.90	0.60	GLM	1.26	0.21	0.75
Rwanda	1.57	0.91	0.66	GAM	1.97	0.66	0.73
Senegal	1.49	0.92	0.68	GAM	1.48	0.31	0.57
Sierra Leone	1.59	0.93	0.80	GLM	2.10	0.09	0.83
South Africa	1.66	0.94	0.42	GLM	2.24	0.62	0.91
Swaziland	1.38	0.81	0.80	GLM	1.55	0.67	0.75
Togo	1.15	0.89	0.60	GLM	1.71	0.31	0.58
Uganda	1.54	0.90	0.62	GAM	1.60	0.52	0.56
UR Tanzania	1.75	0.91	0.76	GAM	1.63	0.44	0.64
Zambia	1.34	0.91	0.60	GAM	1.60	0.68	0.70
Zimbabwe	1.44	0.83	0.60	GAM	1.60	0.72	0.54

Source: Birth histories (adjusted for HIV-related biases) and sibling histories from DHS.

8. Comparison of our mortality estimates with those derived from the IGME, WPP and GBD.

This section provides a brief assessment of the direction and magnitude of differences between our estimates of ${}_5q_0$ and ${}_{45}q_{15}$ and the following: those produced by the International Inter-Agency Group for Child Mortality Estimation (IGME); those calculated by the United Nations Population Division during the 2010 revision of *World Population Prospects* (referred to here as WPP); and the estimates produced by the Institute for Health Metrics and Evaluation as part of the 2010 Global Burden of Disease study (GBD). To compare different sets of estimates, relative differences were computed as follows. Given two values, x and y , their relative difference is expressed as: $(x - y) / \text{mean}(x, y)$.

Figure S4 compares our estimates of ${}_5q_0$ for both sexes combined, derived from full birth histories recorded in the DHS, with the IGME and GBD estimates. For only 25 per cent of the points plotted in the left-hand graph is the relative difference between the IGME estimate and our estimate greater than ± 10 per cent. In the right-hand graph, where our estimates are plotted against the GBD estimates, 30 per cent of the points plotted show a relative difference greater than ± 10 per cent. Our estimates tend to be higher than IGME and GBD estimates: on average, the ratio of our estimates to IGME estimates is 1.04 and the mean of relative differences is 0.03. The corresponding values when our figures are compared with those from the GBD are 1.08 and 0.07. We attribute our higher figures to the adjustment we introduced to account for the under-reporting of deaths and to the absence of any correction to account for HIV-related biases in the GBD figures.

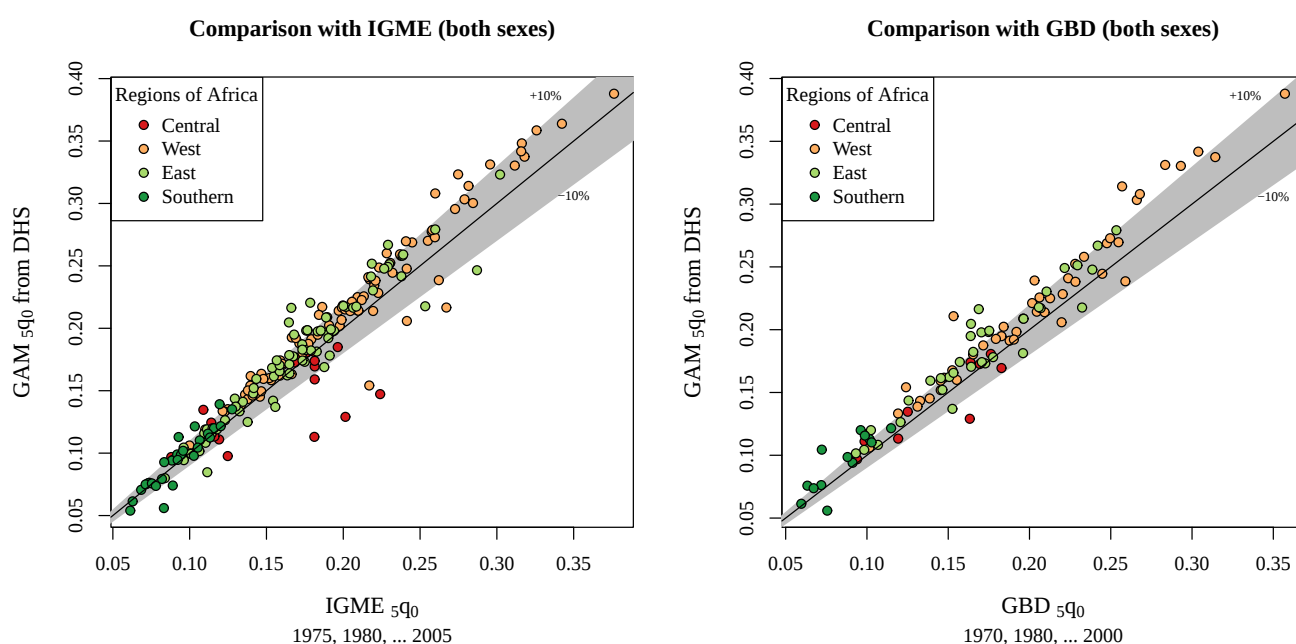


Figure S4 Our estimates of ${}_5q_0$, using full birth histories from DHS compared with estimates from the IGME (for successive five year periods from 1975 to 2005) and from the IHME for the GBD 2010 study (for successive 10-year periods from 1970 to 2000), individual countries, by region, sub-Saharan Africa.

Sources: As for Figure S2.

Larger differences appear when adult mortality and child mortality rates are considered separately for each sex. Figure S5 presents, for each sex, the relative differences in ${}_5q_0$, plotted on the x-axis, compared

with the relative differences in $_{45}q_{15}$, plotted on the y-axis. Because the IGME have only published sex-specific estimates for 1990 and 2011, the estimated under-five mortality rates shown in Figure S5 are taken from WPP. These estimates tend to be slightly higher than those computed by the IGME.

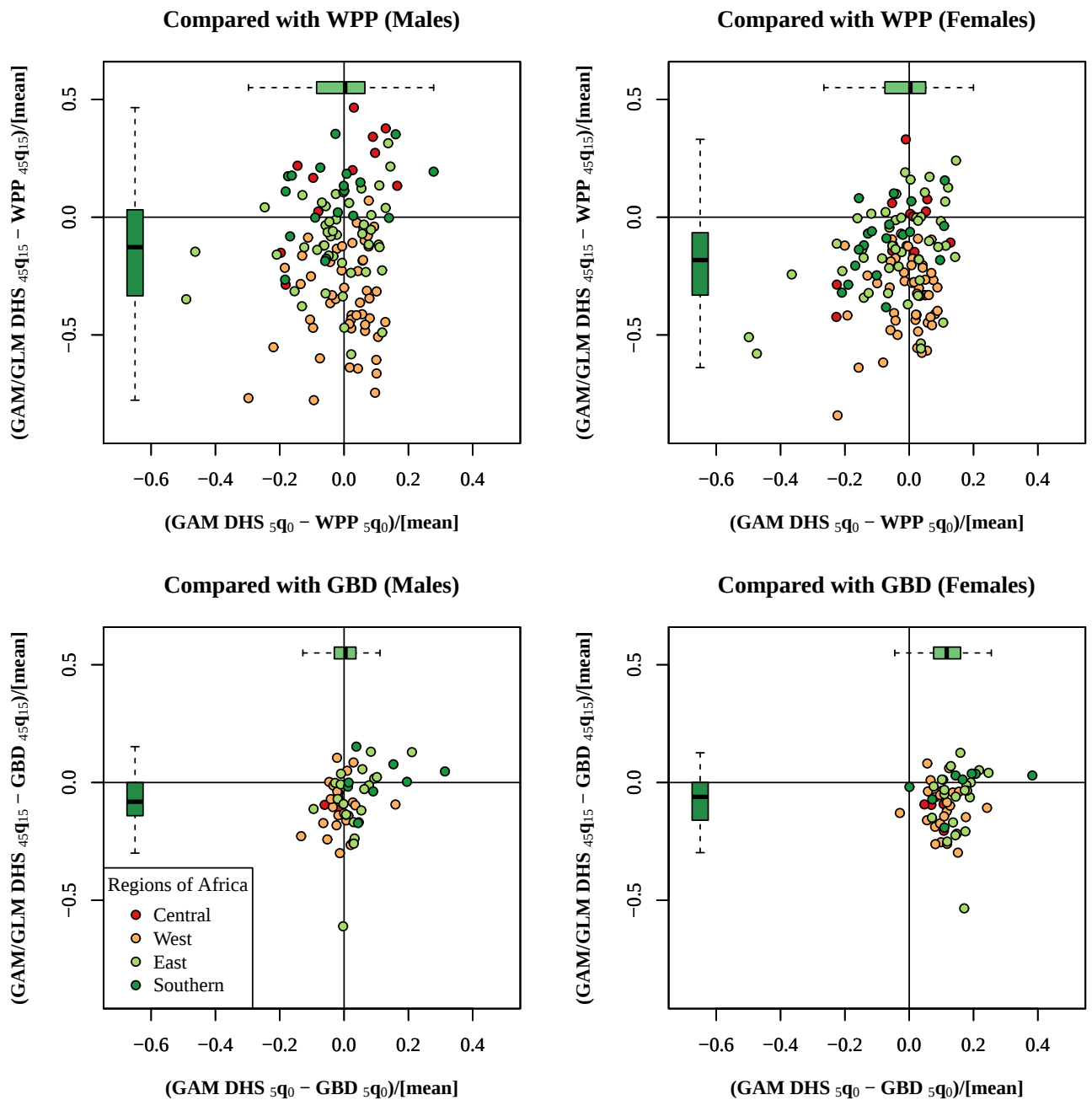


Figure S5 Relative differences in $_{5}q_0$ and $_{45}q_{15}$, by sex, individual countries in sub-Saharan Africa, by region:

Upper Panel: the relative differences between our estimates derived from DHS birth and sibling histories and those from the 2010 Revision of the *World Population Prospects* (WPP) for successive five year periods from 1978 to 2008

Lower Panel: the relative differences between our estimates derived from DHS birth and sibling histories and those from the IHME 2010 Global Burden of Disease (GBD) Study, for successive 10-year periods from 1980 to 2000.

Source: As for Figure S2 and S3 *Note:* The denominator noted '[mean]' refers to the mean of our estimates and GBD or WPP estimates. For example, in the upper left graph, it is the mean of our estimates of $_{5}q_0$ for males and the corresponding estimates from the WPP. The key identifying regions in the lower left graph relates to all four graphs.

A first observation concerns sex differences in child mortality, ${}_5q_0$. In the GBD, the male-to-female ratio of child mortality is concentrated around 1.2, and tends to be higher in countries where child mortality is higher. This is the inverse relationship of the relationship found in historical data (Hill and Upchurch 1995) and data from the WPP and IGME (Sawyer 2012), and our DHS estimates.

Other conspicuous discrepancies concern our estimates of ${}_{45}q_{15}$ and those produced by the UNPD. For half of the data points, the relative differences are larger than ± 20 per cent for females, and larger than ± 18 per cent for males. There are important variations across regions: among females, relative differences vary from -5 per cent, on average, in Central Africa to -32 per cent in West Africa. For males, the mean of relative differences is negative in East Africa (where it is -10 per cent) and West Africa (-33 per cent) but positive in Central Africa (16 per cent) and Southern Africa (8 per cent). We suggest several possible explanations for this in the main text.

There is a greater congruence between our estimates of adult mortality and those calculated by the GBD, but the latter are still higher than the former. In the GBD, sibling estimates were computed for three periods of five years before each survey, assuming that mortality was constant within each period. Adjustments for selection biases were used but several aspects of this procedure remain unclear, including how reports on brothers were adjusted and by how much raw estimates were corrected. To evaluate how the quality of reporting declines with the time elapsed since a death, Wang et al. (2012) used a procedure comparable to the one adopted here, although we do not know the coefficient they used to adjust mortality rates upwards. In addition to using sibling histories, Wang et al. (2012) also derived estimates via death distribution methods (DDMs). These were based on a comparison of the age structure of the populations of the countries they were studying and the distribution of age of deaths occurring in households as reported in censuses and surveys conducted in those countries (Bennett and Horiuchi 1984; Hill 1987; Murray et al. 2010). In several instances, Wang et al.'s estimates were considerably higher than those obtained from DHSs (Malawi, Mozambique, Cameroon, Mali), but at present it is unclear whether this was due to the poor quality of reporting in DHS sibling histories or to an overestimation of mortality from recent household deaths resulting from excessive adjustments to compensate for under-reporting.

Owing to the paucity of data on adult survival in sub-Saharan Africa, large differences in estimates of the prevailing rates are inevitable. If anything, the differences are informative from a measurement perspective because they provide compelling examples of the sensitivity of estimates to underlying assumptions and to errors in the data. However, it is important to understand why mortality estimates differ to such a large extent. Systematic variations may point to biases and indicate where the methods requires further development. Better understanding of reasons for the differences may also lead to improvements in the collection of data on adult mortality in censuses and surveys.

9., Trends in under-five mortality rates from all causes and from malaria-related causes at Health and Demographic Surveillance Sites in Senegal

The cause of any death occurring at three Senegalese HDSSs (Bandafassi, Mlomp, and Niakhar) is determined by a verbal autopsy (VA). Although malaria has some symptoms in common with other diseases, reliable estimates of mortality attributable to this disease were obtained in Niakhar (Trape et al. 2012). In the Sahel and sub-Saharan, rains occur only during a short period of the year, so there is a distinct seasonal peak of childhood deaths preceded by high fever, seizure, and/or coma when, a few weeks after the rains, malaria-carrying mosquitoes increase massively in number. This helps the

diagnosis of malaria to be made with much greater sensitivity and specificity than in areas where rain occurs all year round. In Mlomp, malaria-related mortality can also be accurately monitored because the parents of many children dying from bouts of fever sought advice at the local health centre where biological tests (using thick blood films) could be undertaken to confirm the malaria diagnosis (Pison et al. 2013). In Bandafassi, these tests could not be performed and the estimates of mortality attributable to malaria in that HDSS are therefore less reliable and are not presented in Figure S6, which shows trends in under-five mortality rates from all causes and from malaria-related causes at the Health and Demographic Surveillance Sites in Senegal

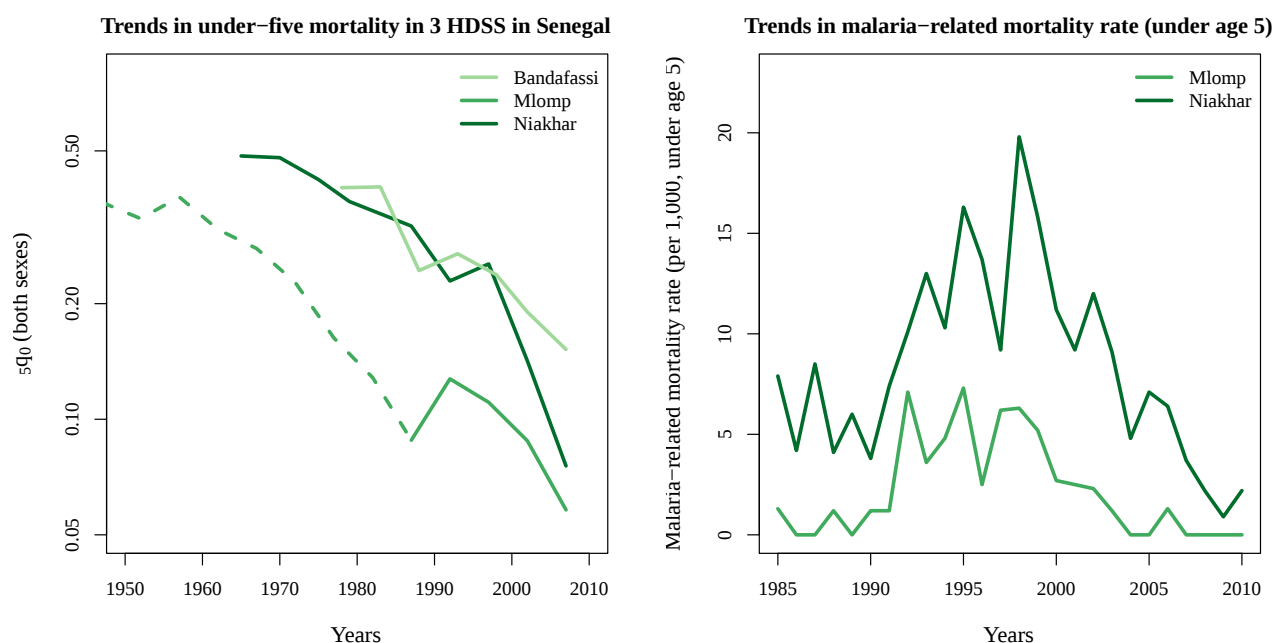


Figure S6 Trends in all-cause under-five mortality rates (1950-2007) and malaria-related under-five mortality rates (1985-2010) at Bandafassi, Mlomp, and Niakhar Health and Demographic Surveillance Sites, Senegal.

Note: Estimates are for five-year periods in the left-hand graph and for one-year periods in the right-hand graph. For Mlomp, estimates for the period before 1985 are derived from birth histories collected retrospectively in 1985, for subsequent years, they were calculated from an annual follow-up.

Trends for Bandafassi are not shown in the right hand graph (see text).

Source: Pison et al. (2013).

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