The Population of Centenarians in Brazil: Historical Estimates from 1900 to 2000

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*Since the nineteenth century, the census has provided the number of 100-year-olds in Brazil, one of the most populous countries worldwide. In 1900, 4,438 individuals reported themselves to be centenarians, a figure that increased about fivefold by the 2000 census. However, due to data quality issues, we are skeptical about the real size of the recorded population in the Brazilian census. We offer alternative estimates of the most likely number of centenarians during the twentieth century by combining variable-*r *relations with different mortality models. Our results indicate there was virtually no centenarian at the beginning of the twentieth century. The population has become larger than 1,000 individuals only in the 1990s, suggesting there has been an extensive, although diminishing, overenumeration of centenarians in the census records. Our results can help policymakers to plan the demands of a growing old age population in places that face stricter family and public budget constraints.*

Introduction

The number of people reaching the age of 100 has called the attention of scientists, including many demographers. In 1990, nearly 90,000 centenarians were living in the world. Over the last 25 years, this number increased almost five times, reaching more than 410,000 people in 2015 (United Nations [UN] 2019). Not surprisingly, given the historical and regional patterns of survival gains, there is a concentration of elderly populations in wealthy, low-mortality regions. However, between 1990 and 2015, the number of centenarians increased by 10 percent more in middle-income than in high-income countries (UN 2019). This pattern highlights the relevance of the growing number of people at very old ages in developing regions.

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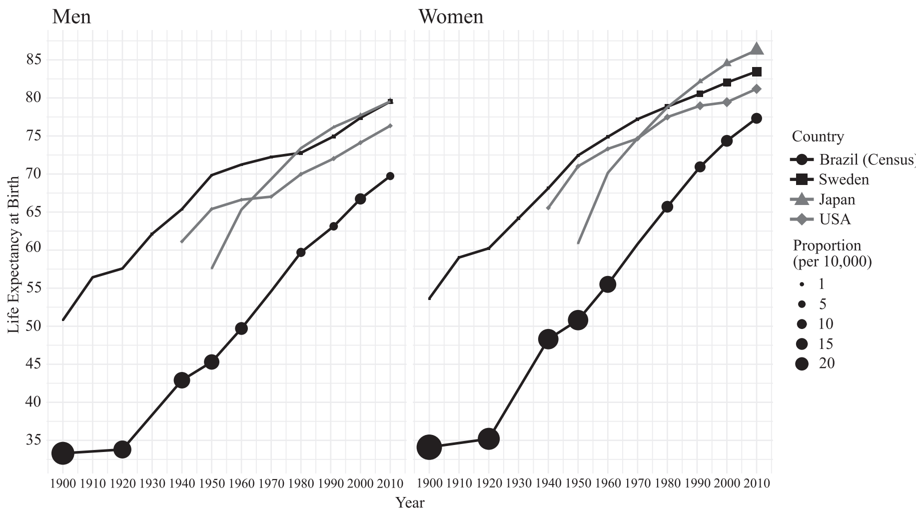
Vaupel and Gowan (1986) were among the first authors to foresee the growth in the number of centenarians by simulating scenarios of survival gains in the United States. A few years later, Thatcher (1992) reported an increasing number of centenarians in England and Wales, particularly after World War II. Since then, other studies have examined trends and patterns of the centenarian population in several today's low-mortality countries (Johnson and Hogan 2020; Medford et al. 2019; Barbi et al. 2018; Leeson 2017; Poon and Cheung 2012; Robine et al. 2010; Rau et al. 2008; Robine, Saito, and Jagger 2009; Drefahl et al. 2012; Jdanov et al. 2008; Kestenbaum and Ferguson 2005; Robine and Saito 2003; Thatcher 2001; Wilmoth 1995; Wilmoth and Lundström 1996; Skytthe and Jeune 1995).

The interest in factors driving the proliferation of centenarians has been increasing, as well. According to Preston and Coale (1982), population growth is due to a combination of changes in births, migration, and mortality rates. In the case of the centenarian population, improvements in survival from aged 80 to 100 appear to be the main factor behind the growing number of individuals (Vaupel and Jeune 1995). Other authors have also stressed the role of declines in late-adult mortality, and the postponement of age-at-death to determine the size of the centenarian population (Kannisto et al. 1994; Robine and Paccaud 2005; Robine and Cubaynes 2017). In Japan, where the distribution of deaths shifted substantially to older ages between 1980 and 2000 (Robine and Cubaynes 2017), the number of centenarians increased 14-fold, from 913 to 13,036 (Robine and Saito 2003).

In the decades to come, we can also expect a steady proliferation of centenarians in middle-income countries, where the mortality transition—from infant and early-adult to late-adult and old ages—started later but it is in progress. There have already been some reports about the multiplication of the number of centenarians in China (Wang et al. 1998), Cuba (Calzadilla et al. 2013), and in other countries like Mexico, Russia, and Poland (Herm, Cheung, and Poulain 2012). In Brazil, according to the census data, there were almost twice as many centenarians in 2010 (24,236) than in 1991 (13,296) (Instituto Brasileiro de Geografia e Estatistíca [IBGE] 1994, 2011). However, confounding data errors have precluded a more in-depth examination of the determinants of demographic trend in middle-income countries, where the vital registration systems are usually weaker. The main reason is the low quality of population counts at older ages due to coverage and content errors, including age misreporting (Turra 2012).

In the case of Brazil, 70 years ago, Mortara (1949) was already very skeptical about the quality of the population enumerated by age in the 1920 and 1940 Census, particularly at older ages. He projected backward the number of births and the probabilities of surviving for different cohorts to estimate what would have been the number of native-born Brazilians by age in both years and compared them to the census figures. Concerning the centenarians, the results were astonishing: he estimated about six and nine

FIGURE 1 Life expectancy at birth and proportion of centenarians among the population aged 60 or more: Brazil and selected countries, men and women, 1900–2010



SOURCE: Author's calculations based on HMD (2020) and Brazilian Census Data.

people, respectively, for 1920 and 1940, whereas both censuses counted more than six thousand individuals. Unfortunately, problems in population enumeration at older ages have not been solved. Gomes and Turra (2009) compared the number of centenarians in the 1991 Brazilian census with extinct generation estimates based on the number of cohort deaths in the following years. The results show substantial discrepancies between the two data sources: about three times more centenarians in the census than registered deaths. Since the death files are also not immune to both coverage and content errors, it remains unclear what it is the most likely size of the centenarian population in Brazil.

A comparison of the proportion of centenarians to the population aged 60 or more in Brazil and today's low mortality countries, as presented in Figure 1, helps to bring to light limitations of census data. Although life expectancy at birth was considerably lower in Brazil than in the selected low mortality countries, the proportion of centenarians was much higher, particularly in the earlier decades of the twentieth century. Over time, mortality levels declined, and the proportion of centenarians increased in Sweden, Japan, and the United States. The opposite trend happened in Brazil, probably as a result of improving census data quality.

The study of the relationship between the number of centenarians recorded in the census and data quality issues is not new and has received extensive attention also in wealthier nations. In the United States, estimates of the number of centenarians showed that the census population was overestimated by about three times in 1960 (Myers 1966). Also, for the United States, some studies have used death statistics and extinct generations methods to confirm the existence of data quality issues at older ages, particularly for some population subgroups such as African Americans (Siegel and Passel 1976). The norm has been age overstatement in census data relative to deaths, although the magnitude of the exaggeration has varied over time (Elo and Preston 1994; Rosenwaike 1979; Rosenwaike and Logue 1983). Not only the United States, but also the Canadian census has overcounted the number of centenarians, particularly the number of semi-supercentenarians (Bourbeau and Lebel, 2000).

The absence of reliable estimates of the centenarian population in populous countries, which have witnessed rapid demographic transitions but lack accurate data, prevents a more comprehensive discussion on the dynamics of these subgroups beyond the limited set of lowest mortality countries. It also hinders local governments from planning policies to reach the demands of a growing old population in places that usually face stricter family and public budget constraints. In the case of Brazil, there are at least three other reasons that justify the estimation of what may have been the evolution of the centenarian population over the decades. First, the country has developed a comprehensive welfare system since the 1980s, which has resulted in one of the relatively largest flows of intergenerational transfers to the elderly in the world (Turra, Queiroz, and Rios-Neto 2011). Consequently, poverty rates are low at older ages in Brazil compared to other middle-income countries, and the empowerment of the elderly has been a frequent topic of debate. However, the country still lacks information about the precise number of people in the oldest age groups, precluding us from measuring the future consequences of population aging effectively. Moreover, as in other countries where data are deficient, age misreporting is probably the main reason why death rates increase slower with age in Brazil than in high-quality data countries (Coale and Kisker 1986; Dechter and Preston 1991; di Lego, Turra, and Cesar 2017; Preston, Elo, and Stewart 1999; Turra 2012). By scrutinizing population census data, one can provide essential clues on the severity of mortality bias in the largest country in Latin America. Finally, Brazil offers a unique setting for studying long-lived population subgroups outside Europe, Japan, and North America because it combines extreme levels of inequality with broad demographic and regional diversity, and rapid social, economic, urban, mortality, and health transitions. However, any study on longevity in Latin America needs to start from meticulous analysis of the size of the oldest-old population.

In the following, we use variable-*r* relations (Preston and Coale 1982; Horiuchi and Preston 1988; Preston, Heuveline, and Guillot 2001) to estimate the centenarian population in Brazil from the combination of different mortality schedules. Our results show a range of estimates which may reasonably be expected to bracket the correct number of centenarians over 1900–2000. Moreover, we point out the differences between our set of estimates and the reported number of centenarians in the Brazilian censuses between 1900 and 2000. We hope our findings stimulate the statistical agencies to improve even further the process of obtaining information about older populations everywhere.

Methods and data

The variable-*r* method

Variable-*r* relations can be of great value in the estimation of population measures when data are missing or are of bad quality. Also, they allow the re-establishment of stationary conditions in nonstable populations, which is especially useful for demographic measurement in the context of the demographic transition. The connection is made by the set of age-specific growth rates, defined by the relationship between the sizes of the population at each age group in two points in time (Preston et al. 2001):

$$e^{\int_0^t \bar{r}(x,t)dt} = \frac{{}_nN_x(t)}{{}_nN_x(0)}, \tag{1}$$

where ${}_nN_x(0)$ and ${}_nN_x(t)$ are the populations at age group x and $x+n$, respectively, at time 0 and t, and $\bar{r}(x,t)$ is the mean age-specific growth rate over time intervals for the age group x and $x+n$.

One of the applications of variable-*r* methods is to express the number of individuals at any age at a given time t in terms of the number of people at another age at the same time t, age-specific population growth rates, and the probability of surviving between those ages (Preston and Coale 1982). The set of age-specific growth rates provides a "growth correction" by adjusting for any differences in the size of the two birth cohorts that come from variations in the number of births, and in cumulative differences of mortality and migration rates. In the words of Preston et al. (2001): "... all the pertinent history is contained in the age-specific growth rate function." Thus,

$${}_nN_x(t) = {}_nN_y(t)e^{-\int_y^x \bar{r}(a,t)da}\,{}_{x-y}p_y(t), \tag{2}$$

where ${}_nN_x(t)$ is the population at age group x and $x+n$ at time t, ${}_nN_y(t)$ is the population aged y and $y+n$ at time t, which $x > y$, $\bar{r}(a,t)$ is the mean age-specific growth rate over time intervals, and ${}_{x\text{-}y}p_y(t)$ is the conditional probability of surviving from ages y to x at time t.

We follow Preston et al. (2001) to adapt Equation 2 to discrete time intervals and estimate the population of centenarians in Brazil. We applied it in two steps. First, we calculated the population 100–109 years old, and, next, the number of individuals 110 to 119 years old. We assumed no individual survived to ages beyond 119 in Brazil during the period of analysis. In low mortality settings, only one woman has been officially verified as older than 120 (International Database on Longevity [IDL] 2020). Since Brazil lags developed countries in terms of mortality levels, it is most likely that there were no Brazilians above such advanced age during the twentieth century.

We present results by sex for the years that correspond to the census' years 1900, 1920, 1940, 1950, 1960, 1970, 1980, 1990, and 2000. The Brazilian census bureau (IBGE) has a long tradition of collecting household data. The first national census occurred in 1872. Since then, data on sex, age, race, civil status, and educational level has been collected almost every 10 years (Oliveira 2003). Only in 1910 and 1930, the census bureau canceled the data collection due to political and economic reasons. Also, the decennial census was postponed from 1990 to 1991 and will be rescheduled from 2020 to 2021 because of the COVID-19 pandemic. IBGE is considered one of the best statistical agencies in the developing world because of its long tradition in collecting different types of household and administrative data, its high degree of independence and autonomy, and the quality of its human resources. Yet, it was only in 1889 that Brazil declared a republic and that the separation of church and state effectively started. Since then, the vital registration system has been slowly developed in the vast and unequal Brazilian territory. Besides, the universalization of education is a relatively new process. It is therefore not surprising that the quality of census data, including coverage and content errors, varied according to the evolution of the country's institutional, demographic, economic, and social contexts over the twentieth century.

At least one earlier study applied population models to measure the number of centenarians. Wilmoth (1995) estimated from a historical perspective when the first centenarian lived on earth. He assumed a stable population model based on a constant rate of growth, which is a reasonable premise for the pre-Industrial period. Because of the demographic transition, the assumption of an age-constant growth rate does not hold for Brazil during the twentieth century.

Also, in a nonstable context, all the terms of Equation 2 must be considered time variant. As a result, the size of the population at age group x and $x+n$ at time t may change over time, which can be shown by taking derivates with respect to time:

$$ {}_{n}\dot{N}_{x}(t) = {}_{n}\dot{N}_{y}(t) - \left[\int_{x}^{y} \bar{r}(a,t)\,da\right]' + {}_{x-y}\dot{p}_{y}(t), \tag{3} $$

where the notation of the apostrophe represents the derivative with respect to time t, and the notation of the dot on top of a variable represents the relative change of the variable of interest. We present the derivation of Equation 3 in the online Appendix containing supplemental material.

Equation 3 indicates that changes in ${}_nN_x$ over time, modeled through variable-*r* relations, is given by relative changes in three terms. First, it depends on the size of the population enumerated in the age group *y*, *y*+*n*, which varies not only because of real demographic changes but also due to improvements in coverage and quality of census data over time. ${}_nN_x$ is also sensitive to changes in the pattern of errors in the enumeration of successive censuses that may affect the age-specific growth rates. Finally, it varies because of improvements in the probability of surviving from ages *y* to *x*. Therefore, Equation 3 offers a guideline to perform the sensitivity analysis and criticize the results presented in the current study.

In what follows, we describe how we define the inputs of Equation 2: (i) the lower limit age *y*, (ii) age-specific growth rates, and (iii) the conditional probabilities of surviving. Also, by detailing each input of Equation 2, we discuss the data we used to estimate each one of them. After having defined the inputs, we build a baseline scenario. Later, we present alternative scenarios to test how the number of centenarians would vary by changing the inputs, as suggested in Equation 3.

The (lower limit) age *y*

As a first step, we must define age *y* in Equation 2. In the baseline scenario, we estimated the number of centenarians from the number of people in the age group 50–59. Although this choice may look arbitrary, there are a few reasons for selecting a middle adult age group instead of younger or older age groups. First, demographers have documented the undercount of children in census data, particularly in developing countries (Oliveira et al. 2003; O'Hare 2015.). Second, Brazilian adolescents and young adults have been exposed to substantial risk of death from external causes, which could add extra uncertainty to our survival estimates (Neves and Garcia 2015). Third, while improvements in late-adult mortality have been the main factor responsible for the proliferation of centenarians (Robine and Cubaynes 2017; Vaupel and Jeune 1995), age overstatement tends to increase with age (Agostinho 2009). Therefore, we also refrained from starting at a more advanced age group. To mitigate arbitrariness in the choice of the age *y*, we performed a sensitivity analysis, as described below, by varying the lower age group and the corresponding population and mortality measures.

We used 10-year wide age intervals to minimize any age misreporting effects further. The number of people in the age group 50–59 was drawn from each successive census collected in Brazil, between 1900 and 2000 (Ministério da Agricultura, Indústria e Comércio, Brasil 1927, 1928; IBGE 1950, 1956, 1960, 1973, 1981a, 1994, 2001, 2011).

Age-specific growth rates

Next, we estimated the set of mean annualized age-specific growth rates above age *y*, for every intercensal period. Even if the size and the age distribution of the population are biased in the census, we can apply the variable-*r* relations as far as the pattern of data errors does not change substantially over time, affecting the age-specific growth rates (Preston et al. 2001). To mitigate any potential bias in the growth rates from the variation of census data quality over time, in the baseline scenario we estimated mean annualized age-specific growth rates for 10-year age groups up to the age group 80–89. At the oldest age, enumeration and age misreporting issues are more prevalent. Thus, for ages older than 90, we replaced age-specific growth rates with the annualized mean growth rate for all aged 90 and above. We tried different open-ended age intervals in the sensitivity analyses, as we detailed below.

We used census data to calculate the set of age-specific growth rates (Ministério da Agricultura, Indústria e Comércio, Brasil 1927, 1928; IBGE 1950, 1956, 1960, 1973, 1981a, 1994, 2001, 2011).

We wanted to make estimates separately for each census year, rather than for intercensal periods. Therefore, we used two intercensal growth rates that are centered on each census date to calculate the mean growth rates. For example, for the age-group 70–79 in 2000, we used the mean growth rate at aged 70 to 79 in 1991–2000 and 2000–2010. Also, because in the first 40 years of the analysis, census observations are separated by 20 years (1900–1920 and 1920–1940), we calculated mean annualized 20-year age-specific growth rates. Moreover, we assumed that age-specific growth rates for the period 1900–1920 apply to 1900.

Conditional probability of surviving

The third parameter in Equation 2 is the conditional probability of surviving. To conclude the estimation of the number of centenarians, we computed life table survivorship ratios from ages 50–59 to age groups 100–109 and 110–119.

Both coverage and content data errors (Agostinho 2009; Gomes and Turra 2009; Horta 2012) preclude us from estimating unbiased mortality rates at older ages directly from deaths and census data. Therefore, to mitigate data quality issues, we applied and compared two main methodological strategies to estimate the mortality functions: (i) the UN version of the Coale–Demeny Model Life Tables (UN 2017) based on the four regional patterns for the years 1900 to 2000; and (ii) three different mathematical representations of mortality—Gompertz, Weibull, and Kannisto models—for the year 2000.

The UN version of the Coale–Demeny Model Life Tables extended the original mortality levels to include life expectancy at birth up to 100 years. We decided not to choose one specific model (i.e., South, North, West, or East). Instead, we offer estimates based on all four patterns. To select the correct mortality level for each regional pattern in every census year, we used two different and complementary parameters: (i) the life expectancy at birth and (ii) the life expectancy at aged 50.

In the baseline scenario, we used e_0 and life expectancy at age 50 (e_{50}) calculated by the Brazilian Census Bureau. The e_0 was considered for all years included in the analysis (1900–2000), and e_{50} for all the years since 1940 (IBGE 1981b, 2004, 2010, 2017). The life expectancy at aged 50 is an index of adult mortality, and, thus, more likely to be associated with the size of the centenarian population. However, it can be more affected by data errors at later ages, and it is not available from 1900 to 1930. Since methodological procedures to adjust death and population counts may change among various studies, particularly for the earlier years of the twentieth century, in the sensitivity analyses, we tested for estimates of life expectancy available from alternative sources.

In addition to the estimates based on Coale–Demeny Model Life Tables, we calculated survival functions by fitting three mathematical functions to Brazilian mortality rates: Kannisto, Gompertz, and Weibull. There is a general agreement that mortality increases exponentially from midadult to aged 80–90, as described by the Gompertz law. However, there is not a consensus regarding the mortality trajectory at the most advanced ages (Barbi et al. 2018; Gampe 2010; Gavrilova and Gavrilov 2015; Gavrilov and Gavrilova 2011; Robine and Vaupel 2001; Vaupel et al. 1998). Most studies suggest that the exponential growth of mortality with age is followed by a period of deceleration, with slower rates of mortality increase at the oldest ages (Barbi et al. 2018; Gampe 2010; Robine and Vaupel 2001; Vaupel et al. 1998). Conversely, another group of researchers has contended that mortality deceleration in later life is a consequence of more inferior data quality at older ages, and that in reality mortality continues to grow exponentially at the highest ages (Gavrilov and Gavrilova 2011; Gavrilova and Gavrilov 2015). As a way to address the current disagreement in the literature, we decided to offer estimates for the number of centenarians in Brazil from the application of the three different mortality models.

To estimate the parameters of the mathematical models, we used official life tables calculated by the IBGE (2013). We fitted the mathematical models to the death rates for the aged 70 to 90+ and then extrapolated the results to the advanced ages. To avoid adding bias from mortality data errors, which were more prevalent in the earlier years, we limited the mathematical estimates to the year 2000.

After having defined all the inputs of the baseline scenario, we summarize it in Table 1.

TABLE 1 The baseline scenario for the estimation of centenarians in Brazil, variable-*r* method

Baseline Scenario	
Lower age limit (y)	50
Age interval of the age-specific growth rates	*y* to 90+
Age-specific growth rates	Mean annualized 10-year age-specific growth rates for the period 1940–2000 Mean annualized 20-year age-specific growth rates for the period 1900–1920 and 1920–1940 Age-specific growth rates for the period 1900–1920 apply to 1900
Conditional probability of surviving	Coale–Demeny Model Life Tables (North, South, West, East) for the period 1900–2000 Kannisto, Gompertz, and Weibull for the year 2000
Mortality index	e_0 for the period 1900–2000 e_{50} for the period 1940–2000
Source of mortality index	Brazilian Census Bureau

SOURCE: Author's elaboration.

Sensitivity analysis

As anticipated, we ran sensitivity analyses to test for the robustness of our results and offer a range of estimates by varying the inputs of the variable-*r* model. First, in addition to applying the annualized mean growth rate for aged 90 and above, we tested for two different open-ended age intervals: 80 and above (Sensitivity 1) and 100 and above (Sensitivity 2). Table A1 in the online supplemental material Appendix shows the growth rates we used in each scenario. These two alternative scenarios are valuable to investigate the extent to which changes in the pattern of data errors in the population enumerated at the oldest ages, which seems to have occurred in Brazil, affect the estimates.

Second, we changed age *y* by starting the calculations from aged 60–69, instead of 50–59. As we varied the lower age group, we had to obtain the corresponding population estimates from the census data and the life table survivorship ratios for the new age range (Sensitivity 3). This scenario reveals how sensitive is the size of the centenarian population to potential problems in the census enumeration of middle-aged adults ages over time.

Lastly, we developed alternative scenarios to evaluate the effect of varying the sources of life expectancy at birth and at age 50, used as indices to select the mortality level for the Coale–Demeny Model Life Tables. We tested three different sources: (i) Arriaga and Davis (1969) for the years 1900 to 1950 (Sensitivity 4), (ii) Comisión Económica para América Latina y el Caribe (2017 for the period 1950–2000 (Sensitivity 5), and (iii)

TABLE 2 Alternative scenarios for the estimation of centenarians in Brazil

Scenario	Period	Modifications from the baseline
Sensitivity 1*	1900–2000	To calculate growth rates, change open-ended age interval to 80+
Sensitivity 2*	1900–2000	To calculate growth rates, change open-ended age interval to 100+
Sensitivity 3	1900–2000	Change the lower age group to 60–69
Sensitivity 4	1900–1950	e_0 calculated by Arriaga and Davis (*1969*)
Sensitivity 5	1950–2000	e_0 and e_{50} calculated by CEPAL (*2017*)
Sensitivity 6	1990–2000	e_0 and e_{50} calculated by Palloni et al. (*2014*)
Sensitivity 7	1950-2000	Replace variable-*r* estimates by cohort reconstruction

NOTE: *The mortality models Kannisto, Gompertz, and Weibull were applied only in the Scenarios 1 and 2.
SOURCE: Author's elaboration.

Palloni, Pinto, and Beltrán-Sánchez (2014) for the years 1990 and 2000 (Sensitivity 6). Tables A2 and A3 in the online Appendix present the values of the mortality indices used in each scenario.

Despite the efforts to test most sources of errors in our model, there is no guarantee that the age-specific growth rates can be accurately measured in the census data, as coverage and content errors have varied over time. Therefore, to avoid the use of growth rates and offer a set of estimates based on a completely different methodological approach, we also calculated the size of the centenarian population from cohort estimates for the second half of the twentieth century (Sensitivity 7). We reconstructed the possible mortality trajectories for cohorts aged 50 to 59 and 60 to 69 years old from 1900 to 1950 and calculated the number of surviving individuals at ages 100–119 in every decade from 1950 to 2000. Because there are no census data in 1910 and 1930, we interpolated the population at ages 50 to 69 in those years based on the observations from 1900, 1920, and 1940 censuses. We limited our cohort analysis to the life tables calculated from Coale–Demeny Model Life Tables (West Model) since the objective is only to test for potential discrepancies between period and cohort estimations. To approximate the cohort mortality functions, we applied the geometric mean of life table survivorship ratios at the beginning and end of each intercensal period and took the corresponding age-period estimates.

Table 2 presents how the alternative scenarios differed from the baseline and the corresponding period of analysis for each one. After having varied the parameters of the variable-*r* method, and developed cohort estimations, we produced 350 different estimates of the centenarian population for each sex between 1900 and 2000. Tables A4, A5, and A6 in the online Appendix compare all the results.

In the following section we present the main findings by examining population sizes, sex ratios, and the life table survivorship ratios from aged 50–59 to 100–109 under the scenarios previously discussed. We also compare some of our estimates to the population calculated directly from the Brazilian census data.

Results

Table 3 summarizes the estimated number of centenarians by sex, for each year, by showing the average, minimum, and maximum population calculated in the baseline.

Our indirect estimates indicate that there was probably no centenarian in the first two decades of the twentieth century in Brazil. The number of centenarians grew little until 1940 when the mortality transition started to affect both population growth rates and the chances to reach ages 100 and older. It would have been only after 1960 that the number of centenarians had surpassed 100 individuals, reaching some value around 1,000 (between 200 and 2,000) centenarians in 2000, of which approximately 80 percent were women. Between 1900 and 2000, the sex ratio based on our estimates considerably declined from 0.62 to 0.24, because of an increasing sex gap in mortality over the years.

The estimates also confirm an extensive overenumeration in the census records (Table 3). According to the census data, 4,438 centenarians were living in Brazil in 1900, from which 46 percent were men. This census estimate is so large that it was not even reached a century later, according to our most optimistic scenario. Also, the sex ratio of 0.86 in the 1900 census is surprising given the female mortality advantage, particularly at adult ages. This result shows that in the past the overenumeration of older groups was more frequent among men than women.

The implausibility of the census data becomes even more evident in Figure 2. We calculated ratios of the centenarian population enumerated in the census data to our indirect measures estimated based on the variable-*r* method and the cohort approach. The declining ratios for both men and women confirm the implausible numbers in the past and the improvement of census data over the years. In the first decades of the twentieth century, the proportions of centenarians based on indirect estimates were a few thousand times lower than the ones enumerated in the censuses. The mean ratio (census data/estimates) for the year 2000 indicates substantially better census data quality than in the past, but it is still higher than ten.

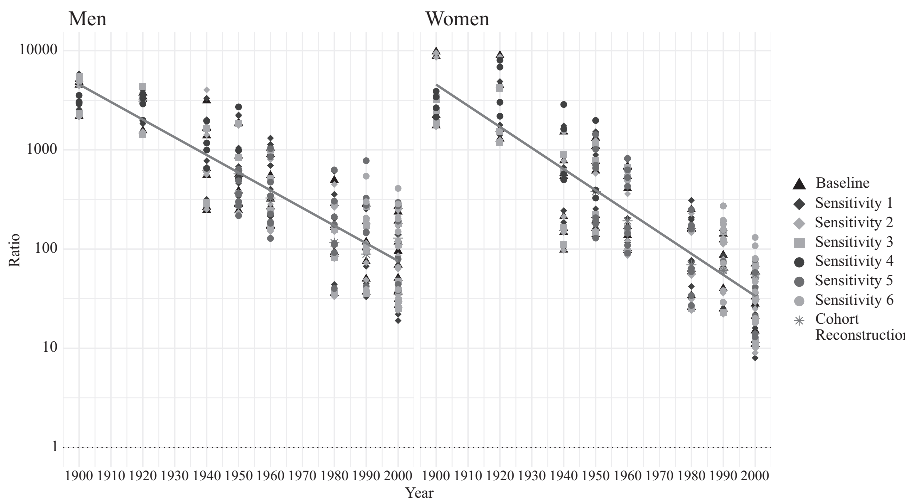
Indirect estimates of the centenarian population also involve uncertainty. Figure 2 reveals the sensitivity of the centenarian population indirectly estimated due to changes in the parameters of Equation 2. Varying the open-ended age group from 90+ to 100+ to calculate the age-specific growth rates or changing the lower age group (lower age limit y) from 50–59 to 60–69 have only minor impacts on the estimated number of centenarians. However, the variation is higher when limiting the open-ended age group from 90+ to 80+. Important differences came up when changing levels of

TABLE 3 The number of centenarians in Brazil: census and indirect estimates, 1900–2000

	Men				Women				Sex ratio	
		Estimated				Estimated				
Year	Census	Average	Minimum	Maximum	Census	Average	Minimum	Maximum	Census	Estimated
1900	2,047	0	0	1	2,391	1	0	1	0.86	0.62
1920	2,625	1	0	2	4,102	2	0	3	0.64	0.46
1940	2,817	5	0	11	4,999	21	3	51	0.56	0.22
1950	3,290	7	2	13	6,399	22	5	46	0.51	0.33
1960	3,483	12	3	21	6,393	33	9	66	0.54	0.38
1970	-	22	5	48	-	65	17	146	-	0.34
1980	3,545	35	7	99	6,705	103	27	256	0.53	0.34
1990	4,253	48	15	115	8,773	168	54	353	0.48	0.29
2000	10,423	180	38	393	14,153	739	198	1,334	0.74	0.24

NOTE: The Brazilian Bureau of Census has not published the number of centenarians for 1970, only the population 99 years and older.
SOURCE: Census Data. Authors' calculations.

FIGURE 2 Ratio of the number of centenarians recorded in the census and indirectly estimated according to different parameters: Brazil, men and women, 1900–2000



NOTE: The dotted line corresponds to an equal number of centenarians recorded in census and indirectly estimated.
SOURCE: Author's calculations.

life expectancy in the early periods of the analysis. For example, in 1940, female life expectancy at birth differed by 11 years, depending on the original study used as our source (the Brazilian Census Bureau or Arriaga and Davis (1969); see Table A2 in the online Appendix). As a result, the size of the female centenarian population varied from 34 to 10 individuals according to the West family of the CD Life Tables (Table A5 in the Appendix).

On the positive side, cohort reconstructions based on the West family of the CD Life Tables are comparable to the variable-*r* estimates (Table A6 in the Appendix). Among men, from 1950 to 2000, the difference between the number of centenarians is lower than 10 individuals using variable-*r* instead of cohort measures. Among women, the difference is lower than 12 persons for the years 1950 to 1990. However, for the year 2000, there is a more considerable discrepancy. We estimated 425 and 258 women using, respectively, variable-*r* and cohort approaches. This isolated result may reflect a combination of factors, including the inadequacy of the life table model, the increasing sex differences in mortality in more recent years, and changes in census coverage at older ages between 2000 and 2010 that affected the age-specific growth rates.

By analyzing Table 3 and Figure 2 together, we show that a substantial portion of the variation in our results comes from the choice of the adult mortality model. For instance, in 1960, the number of centenarians varies from 12 to 87 only due to changes in the mortality schedules. Therefore, the idea of providing a set of population estimates by changing the mortality

FIGURE 3 Life table survivorship ratios calculated from selected mortality schedules: Brazil, men and women, 1900–2000

SOURCE: Author's calculations.

models was not only to uncover our ignorance about the actual mortality function at older ages in Brazil but also to measure the extent to which census data are implausible.

Figure 3 confirms the high degree of uncertainty concerning survival levels. It plots life table survivorship ratios from ages 50–59 to 100–109 used in our study. The survivorship ratios derived from the Coale–Demeny model North, Kannisto, and Weibull models are the highest among all estimates. This result is not surprising since Coale–Demeny North reflects conditions that are typical of countries that experience lower mortality at older ages. Besides, the Kannisto model follows the logistic form at advanced ages, and the Weibull model is an intermediate pattern between the exponential and logistic mortality increases at older ages. The lowest survival estimates are the ones calculated from the Coale–Demeny South and East models, since they reflect conditions from countries characterized by higher mortality levels at advanced ages.

Regardless of the mortality model adopted, survival gains have been particularly high among women. For example, the chances of women surviving to ages 100–109 from ages 50–59 improved 34-fold, between 1900 and 2000, according to the Coale–Demeny West Model. However, these gains were not enough to explain a large number of centenarians in the Brazilian censuses. The actual probabilities of surviving would need to be ten- to one thousand times higher than the survival curves adopted in the current work, depending on the year and sex, for census records to be real.

Discussion

There is a general belief in Brazil that the centenarian population has been increasing very rapidly over the last decades. According to the census data, the centenarian population grew two and a half times between 1960 and 2000 and currently comprises more than 24,000 individuals. Whereas the Brazilian population is indeed getting older faster than in many wealthier regions, the estimated centenarian population is probably substantially smaller than the number of individuals counted by the census, having increased from fewer than 100 individuals in 1960 to between 200 and 2,000 people in the year 2000. The slower growth of the centenarian population in the census than predicted by our estimates suggests there have been improvements in data collection over time. Also, the much higher census sex ratios reinforce the hypothesis of the overenumeration of centenarians, particularly men.

Our indirect estimates based on variable-*r* relations are not immune to errors. Age-specific growth rates in Brazil may vary over time due to changes in census data quality, affecting the estimates of the population size at older ages. However, sensitivity analyses, including cohort estimates, indicated that any errors from the methodology are probably not substantial. What affects population estimates at old ages is the choice of the mortality model. To minimize the lack of high-quality mortality data at advanced ages in Brazil, we compared estimates from different mortality schedules. We concluded that unless adult age patterns of mortality are very atypical in Brazil, the number of centenarians in the census records are incompatible with the prevailing adult mortality levels in the country.

There are still very few studies that examine the centenarian population thoroughly in Latin American countries. In Brazil, Mortara (1949) was the first demographer to worry about the poor quality of the population enumerated at older ages in the census, anticipating what would be a crucial subject several decades later. His estimates for the census years 1920 and 1940 are contained within the range of results we presented here. Our study is the first to provide a systematic comparison between indirect estimates and census records of centenarians over a century in Brazil. Although another recent study has examined the enumeration of centenarians, it provides indirect evidence for only one census year (Gomes and Turra 2009). As aforementioned, the authors found that the number of centenarians in census records was triple those in death files in the year 1991. Here, we went beyond their findings in showing that the likely number of centenarians is not only substantially smaller than census records but also lower than the number of deaths registered at agesd 100 and older. Whereas it is not surprising that age misreporting affects the quality of both census data and death files, the bias is proportionally more extensive in the census records resulting in artificially lower mortality rates at older ages, as revealed by Preston et al. (1999) and examined by Turra (2012) in Brazil.

The evolution of the population of Brazilian centenarians across the decades, as measured by the census records, is odd, because of substantial data improvements that have occurred in each new data collection. This inaccurate time trend seems to reflect in the estimates published by the UN in 2019 (2019). According to them, the number of centenarians decreased from almost nine thousand in 1950 to fewer than 100 individuals in 1970, increasing after that. Therefore, we believe the UN figures for the 1950s and 1960s are wrong, although they are substantially more consistent with (somewhat higher than) our estimates for the period 1970–2000. Also, according to the UN (2019) projections, the population of Brazilian centenarians will only reach the number recorded in the 2000 census (about 25,000 individuals) in the year 2025, surpassing 100,000 and 1,000,000 cases, respectively, after 2035 and 2085. The estimation of future trends still needs more scrutiny, since the correct age patterns of mortality at adult ages in Brazil remain a puzzle.

There have always been many false longevity claims in low- and middle-income countries, including Brazil. Therefore, the excess of centenarians in official Brazilian data is consistent with the pattern of many unsubstantiated cases. It reflects the low levels of formal education among Brazilian elderly, the absence of vital registration systems in many geographic areas during the 19th and twentieth centuries, the existence of economic incentives for age exaggeration, and even the inability of the census bureau to collect data from the oldest-old groups. The enumeration of centenarians is central to the study on the limits of the human life span. Not knowing the correct number of the longest-lived people hampers the debate about human longevity. Also, science needs many cases from all continents to form a broader and robust view of survival trajectories under different living conditions. Accordingly, the analysis cannot be limited to the outliers. As for Brazil, Turra (2012) verified the age of a woman who became the oldest person in the world for about a month until her death. However, despite its scientific importance, as an isolated verified case, it provided little information about the actual survival levels at extreme ages. Our article offers a better starting point for studying centenarians in low- and middle-income countries: new parameters of the population beyond age 100 for an entire century in the largest country of Latin America.

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References

Agostinho, Cíntia Simões. 2009. "Estudo sobre mortalidade adulta, para Brasil entre 1980 e 2000 e Unidades da Federação em 2000: uma aplicação dos métodos de distribuição de mortes." PhD diss., Universidade Federal de Minas Gerais.

Arriaga, Eduardo E, and Kingsley Davis. 1969. "The Pattern of Mortality Change in Latin America." *Demography* 6(3): 223–242.

Barbi, Elisabetta, Francesco Lagona, Marco Marsili, James W. Vaupel, and Kenneth W. Wachter. 2018. "Demography of Longevity Pioneers." *Science* 360(6396): 1459–1461.

Bourbeau, Robert, and André Lebel. 2000. "Mortality statistics for the oldest-old." *Demographic Research* 2(2): 1–36.

Brasil, Ministério da Agricultura, Indústria e Comércio. 1927. "Annuario estatistico do Brazil 1927." Directoria Geral de Estatistica 3(1): 1–1053.

———. 1928. "Recenseamento do Brazil realizado em 1 de setembro de 1920: população." Directoria Geral de Estatistica 4(2): 1–925.

Calzadilla, Esmir C., Mercedes Gámez Fonseca, Mailin Borroto, and Consuelo Prado Martínez. 2013. "Characterization of the Nutritional Status of the Cuban Centenarian Population." *Revista Cubana de Investigaciones Biomédicas* 31(4): 459–466.

Comisión Económica para América Latina y el Caribe (CEPAL). 2017. *Life Tables* (Vol. 1). Santiago, Chile: United Nations; 1–212.

Coale, Ansley J., and Ellen Eliason Kisker. 1986. "Mortality Crossovers: Reality or Bad Data." *Population Studies* 40(3): 389–401.

Dechter, Aimée R., and Samuel H. Preston. 1991. "Age Misreporting and Its Effects on Adult Mortality Estimates in Latin America." *Population Bulletin of the United Nations* 31–32: 1–16.

di Lego, Vanessa, Cássio M. Turra, and Cibeli Cesar. 2017. "Mortality Selection among Adults in Brazil: The Survival Advantage of Air Force Officers." *Demographic Research* 37(1): 1339–1350.

Drefahl, Sven, Hans Lundström, Karen Modig, and Anders Ahlbom. 2012. "The Era of Centenarians: Mortality of the Oldest Old in Sweden." *Journal of Internal Medicine* 272(1): 100–102.

Elo, Irma T., and Samuel H. Preston. 1994. "Estimating African-American Mortality from Inaccurate Data." *Demography* 31(3): 427–458.

Gampe, Jutta. 2010. "Human Mortality beyond Age 110." In *Supercentenarians*, edited by Meier H. et al., 219–230. Heidelberg: Springer.

Gavrilov, Leonid A., and Natalia S. Gavrilova. 2011. "Mortality Measurement at Advanced Ages: A Study of the Social Security Administration Death Master File." *North American Actuarial Journal* 15(3): 432–447.

Gavrilova, Natalia S., and Leonid A. Gavrilov. 2015. "Biodemography of Old-Age Mortality in Humans and Rodents." *Journals of Gerontology - Series A Biological Sciences and Medical Sciences* 70(1): 1–9.

Gomes, Marília Miranda Forte, and Cássio M. Turra. 2009. "The Number of Centenarians in Brazil: Indirect Estimates Based on Death Certificates." *Demographic Research* 20(20): 495–502.

Herm, Anne, Karen S.L. Cheung, and Michel Poulain. 2012. "Emergence of Oldest Old and Centenarians: Demographic Analysis." *Asian Journal of Gerontology & Geriatrics* 7(1): 19–26.

Horiuchi, Shiro, and Samuel H. Preston. 1988. "Age-Specific Growth Rates: The Legacy of Past Population Dynamics." *Demography* 25(3): 429–441.

Horta, Cláudia Júlia Guimarães. 2012 "Idade Declarada nos Censos Demográficos e a Qualidade da Informação." *Anais do XVIII Encontro Nacional de Estudos Populacionais* 1: 1–19.

Human Mortality Database 2020. University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany). Accessed March 18, 2020. https://www.mortality.org

Instituto Brasileiro de Geografia e Estatistíca. 1950. "Recenseamento Geral do Brazil 1 de setembro de 1940." Fundação Instituto Brasileiro de Geografia e Estatística 2(1): 1–181.

———. 1956. "Brasil Censo Demográfico de 1950." *Fundação Instituto Brasileiro de Geografia e Estatística* 1(1): 1–334.

———. 1960. "Censo Demográfico de 1960." *Fundação Instituto Brasileiro de Geografia e Estatística* 1(1): 1–138.

———. 1973. "Censo Demográfico de 1970." *Fundação Instituto Brasileiro de Geografia e Estatística* 1(1): 1–267.

———. 1981a. "Sinopse preliminar do Censo Demográfico de 1980." *Fundação Instituto Brasileiro de Geografia e Estatística* 1(1): 1–93.

———. 1981b. "Anuário estatístico do Brasil - 1981." *Fundação Instituto Brasileiro de Geografia e Estatística* 1(1): 1–93.

———. 1994. "Censo Demográfico 1991." *Fundação Instituto Brasileiro de Geografia e Estatística* 1(1): 1–209.

———. 2004. "Revisão 2004 - Tábua completa de mortalidade para o Brasil–2000." Accessed April 10, 2015. https://www.ibge.gov.br/estatisticas/sociais/populacao/9126-tabuas-completas-de-mortalidade.html?edicao=18026&t=publicacoes

———. 2001. "Censo Demográfico 2000: características da população e dos domicílios: resultados do universo." *Ministério de Planejamento, Orçamento e Gestão* 1(1): 1–550.

———. 2010. "Observações sobre a evolução da mortalidade no Brasil: o passado, o presente e perspectivas." *Ministério de Planejamento, Orçamento e Gestão* 1(1): 1–56.

———. 2011. "Censo Demográfico 2010: características da população e dos domicílios: resultados do universo." *Ministério de Planejamento, Orçamento e Gestão* 1(1): 1–270.

———. 2013. "Projeção da população do Brasil por sexo e idade para o período 2000/2060." *Ministério de Planejamento, Orçamento e Gestão* 1(1): 1–21.

———. 2017. "Tábua completa de mortalidade para o Brasil – 2016: Breve análise da evolução da mortalidade no Brasil." *Ministério de Planejamento, Orçamento e Gestão* 1(1): 1–23.

International Database on Longevity 2020. Max Planck Institute for Demographic Research (Germany). Accessed March 18, 2020. https://www.supercentenarians.org.

Jdanov, Dmitri. A., Domantas Jasilionis, Eugeny Soroko, Roland Rau, and James W. Vaupel. 2008. "Beyond the Kannisto-Thatcher Database on Old Age Mortality: An Assessment of Data Quality at Advanced Ages." *MPIDR Working Paper 2008-013*, Rostock, Germany: Max Planck Institute for Demographic Research.

Johnson, Sandra Leigh, and Howard Hogan. 2020 "Babies No Longer: Projecting the 100+ Population." In *Developments in Demography in the 21st Century*, edited by Singelmann J. and D.L. Poston, Jr., 95–103. Cham: Springer.

Kannisto, Vaino, Jens Lauritsen, Arthur Roger Thatcher, and James W. Vaupel. 1994. "Reductions in Mortality at Advanced Ages: Several Decades of Evidence from 27 Countries." *Population and Development Review* 20(4): 793–810.

Kestenbaum, Bert, and Reneé Ferguson. 2005. "Number of Centenarians in the United States 01/01/1990, 01/01/2000, and 01/01/2010 Based on Improved Medicare Data." *Population Association of America* 2005, 1–9.

Leeson, George W. 2017 "The Impact of Mortality Development on the Number of Centenarians in England and Wales." *Journal of Population Research* 34(1): 1–15

Medford, Anthony, Kaare Christensen, Axel Skytthe, and James W. Vaupel. 2019. "A Cohort Comparison of Lifespan after Age 100 in Denmark and Sweden: Are Only the Oldest Getting Older?" *Demography* 56(2): 665–677.

Mortara, Giorgio. 1949. "Comparação entre os números dos brasileiros natos, apurados pelos censos de 1940 e de 1920, e os calculados conforme determinadas hipóteses acêrca da população, da natalidade e da mortalidade." *Revista Brasileira de Estatística* 39: 1–32.

Myers, Robert J. 1966. "Validity of Centenarian Data in the 1960 Census." *Demography* 3(2): 470–476.

Neves, Alice Cristina Medeiros, and Leila Posenato Garcia. 2015. "Youth Mortality in Brazil: Profile and Trends in the Period 2000–2012." *Epimiologia e Serviços de Saúde* 24(4): 595–606.

O'Hare, William P. 2015. "Coverage of Young Children in the Census: An International Comparative Perspective." O'Hare, William P., In The Undercount of Young Children in the U.S. Decennial Census*, 27–37*. Cham: Springer.

Oliveira, Jane Souto. 2003. "Brasil mostra a sua cara: imagens da populacao brasileira nos censos demográficos de 1872 a 2000." *Textos para discussão. Escola Nacional de Ciências Estatisticas* 18(6): 1–75.

Oliveira, Luís Carlos de Souza, Marcos Paulo Soares de Freitas, Márcia Regina Martins Lima Dias, Cláudia Maria Ferreira Nascimento, Edie da Silva Mattos, and João José Amado Ramalho Júnior. 2003. "Censo Demográfico 2000: Resultados da Pesquisa de Avaliação da Cobertura da Coleta." *Textos para discussão, Instituto Brasileiro de Geografia e Estatistica* 1(9):1–143.

Palloni, Alberto, Guido Pinto, and Hiram Beltrán-Sánchez. 2014. "Latin American Mortality Database (LAMBdA)." *University of Wisconsin*. Accessed March 20, 2020. https://www.ssc.wisc.edu/cdha/latinmortality/

Poon, Leonard W., and Karen S.L. Cheung. 2012. "Centenarian Research in the Past Two Decades." *Asian Journal of Gerontology & Geriatrics* 7(1): 8–13.

Preston, Samuel. H., and Ansley J. Coale. 1982."Age Structure, Growth, Attrition, and Accession: A New Synthesis." *Population Index* 48(2): 217–259.

Preston, Samuel. H., Irma T. Elo, and Quincy Stewart. 1999. "Effects of Age Misreporting on Mortality Estimates at Older Ages." *Population Studies* 53(2): 165–177.

Preston, Samuel. H., Patrick Heuveline, and Michel Guillot. 2001. *Demography: Measuring and Modeling Population Processes*. Oxford: Blackwell Publishers Ltd

Rau, Roland, Eugeny Soroko, Domantas Jasilionis, and James W. Vaupel. 2008. "Continued Reductions in Mortality at Advanced Ages." *Population and Development Review* 34(4): 747–768.

Robine, Jean-Marie, and James W. Vaupel. 2001. "Supercentenarians: Slower Ageing Individuals or Senile Elderly?" *Experimental Gerontology* 36 (4–6): 915–930.

Robine, Jean-Marie, and Yasuhiko Saito. 2003. "Survival Beyond Age 100 : The Case of Japan Survival Beyond Age 100 : The Case of Japan. " *Population and Development Review* 29(supplement): 208–228.

Robine, Jean-Marie, and Fred Paccaud. 2005. "Nonagenarians and Centenarians in Switzerland, 1860–2001: A Demographic Analysis." *Journal of Epidemiology and Community Health* 59(1): 31–37.

Robine, Jean-Marie, Yasuhiko Saito, and Carol Jagger. 2009. "The Relationship between Longevity and Healthy Life Expectancy." *Quality in Ageing and Older Adults* 10(2): 5–14.

Robine, Jean-Marie, Karen S. L. Cheung, Yasuhiko Saito, Bernard Jeune, Marti G. Parker, and Francois R. Herrmann., 2010. "Centenarians Today: New Insights on Selection from the 5-COOP Study." *Current Gerontology and Geriatrics Research* 2010(120354):1–9.

Robine, Jean-Marie, and Sarah Cubaynes. 2017. "Worldwide Demography of Centenarians." *Mechanisms of Ageing and Development* 165(B): 59–67.

Rosenwaike, Ira. 1979. "A New Evaluation of United States Census Data on the Extreme Aged." *Demography* 16(2): 279–288.

Rosenwaike, Ira, and Barbara Logue. 1983. "Accuracy of Death Certificate Ages for the Extreme Aged." *Demography* 20(4): 569–585.

Siegel, Jacob S., and Jeffrey S. Passel. 1976. "New Estimates of the Number of Centenarians in the United States." *Journal of the American Statistical Association* 71(355): 559–566.

Skytthe, Axel and Bernard Jeune. 1995. "Danish Centenarians after 1800." In *Monographs on Population Aging* edited by B. Jeune and J. Vaupel, 55–66. Odense: Odense University Press.

Thatcher, Arthur Roger. 1992. "Trends in Numbers and Mortality at High Ages in England and Wales." *Population Studies* 46(3): 411–426.

Thatcher, Arthur Roger. 2001. "The Demography of Centenarians in England and Wales." *Population: An English Selection* 13(1): 139–156.

Turra, Cássio M., Bernardo Lanza Queiroz, and Eduardo L.G. Rios-Neto. 2011 "Idiosyncrasies of Intergenerational Transfers in Brazil." In *Population Aging and Generational Economy* edited by R. Lee and A. Mason. Cheltenham: Edward Elgar Publishing.

Turra, Cássio M., & 2012. "Os limites do corpo: A longevidade em uma perspectiva demográfica." *Revista da Universidade Federal de Minas Gerais* 19(1): 156–181.

United Nations, Department of Economic and Social Affairs, Population Division. 2017. *World Population Prospects 2017*, https://population.un.org/wpp/. Accessed January 20, 2018.

———. 2019. *World Population Prospects 2019*, https://population.un.org/wpp/. Accessed August 12, 2019.

Vaupel, James W., and Ann E. Gowan. 1986. "Passage to Methuselah: Some Demographic Consequences of Continued Progress against Mortality." *American Journal of Public Health* 76(4): 430–433.

Vaupel, James W., and Bernard Jeune. 1995. "The Emergence and Proliferation of Centenarians." In: *Exceptional Longevity: From Prehistory to the Present*, edited by Jeune, B. and Vaupel, J.W., Odense: Odense University Press.

Vaupel, James W., James R. Carey, Kaare Christensen, Thomas E. Johnson, Anatoli I. Yashin, A. I., Niels V. Holm, Ivan A. Iachine, Väinö Kannisto, Aziz A. Khazaeli, Pablo Liedo, Valter D. Longo, Yi Zeng, Kenneth G. Manton, and James W. Curtsinger. 1998. "Biodemographic Trajectories of Longevity." *Science* 280(5365): 855–860.

Wang, Zhenglian, Yi Zeng, Bernard Jeune, and James W. Vaupel. 1998. "Age Validation of Han Chinese Centenarians." *Genus* 54(1–2): 123–141.

Wilmoth, John R. 1995. "The Earliest Centenarians: A Statistical Analysis." In *Exceptional Longevity: From Prehistory to the Present* edited by Jeune, B. and Vaupel, J.W. 1–20. Odense: University Press.

Wilmoth, John R., and Hans Lundström. 1996. "Extreme Longevity in Five Countries: Presentation of Trends with Special Attention to Issues of Data Quality." *European Journal of Population* 12: 63–93.