Chapter 2
Remarks on "Limits to Human Lifespan"

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2.1 Introduction

Following the debate emerged after the publication in Nature of the paper by Dong et al. 2016 on "Evidence for a limit to human lifespan" many interesting remarks came out for further investigating and exploring the supercentenarians population in the time course (see Brown et al. 2017; De Beer et al. 2017; Hughes and Hekimi 2017; Lenard and Vaupel 2017; Rozing et al. 2017).

A part of the debate was related to the data handling, another on the methodological aspects of the statistical methods and techniques used whereas remarks from cases from several scientific fields could also be considered along with beliefs and personal opinions on the existence or not of a lifespan limit. Perhaps, sooner or later, the studies on expanding the lifespan of simpler species will solve the problem. Until then we have summarized in 12 points the main approaches we can handle with today's knowledge on theoretical and applied tools and methods (more details at Janssen and Skiadas 1995; Skiadas and Skiadas 2010a, b, 2014, 2015, 2017).

1. The first we have noticed is that a clearer and "stronger" data handling is needed.
2. Perhaps we have to "see" the same data from a different viewpoint.
3. High dispersion data sets are not very well presented with a linear trend. Even the nonlinear representation is not good as well.
4. Handling and applying Life Table data sets for over 90 years of age is dubious.
5. Simpler is to use the raw death data instead of the death probability data.
6. Next, a data transformation is important before to start more data handling. This is the lesson learned from Gompertz days (Gompertz 1825). A visual inspection in graphs could be more informative.

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C. H. Skiadas, C. Skiadas (eds.), *Demography and Health Issues*,
The Springer Series on Demographic Methods and Population Analysis 46,
https://doi.org/10.1007/978-3-319-76002-5_2

7. Another important future is to inspect the distribution of deaths and especially the tail at the right hand side (Skiadas and Skiadas 2017).
8. As the number of death cases in the tail sharply declines according to age the case could be studied with one of the methods proposed under the term: "extreme value distributions".
9. By these methods relatively simpler logarithmic expressions replace the formulas for the distribution of deaths and are fitted to the data to the last periods of the life span.
10. These distribution methods include a first and frequently a second logarithm of the logarithm, when the decline in the tail is very sharp. Thus by starting the study by first transforming the data in a logarithmic form the complexity of the logarithmic equation form is reduced.
11. Another point is how to handle exceptional cases as that of Jeanne Calment clearly lying at the very edges of Maximum Reported Age at Death (MRAD).
12. We search in the majority of cases that belonging to the normal trajectories with a high probability. But how about the cases with very small probability as for Jeanne Calment? In France with a total centenarians population of 38.712 in the period 1990–2014 we need a thousand times larger population to have a MRAD at 122 years of age. Or simpler the probability is only 1/1000 for the appearance of one MRAD at this age.

2.2 Data Transformation and Application in United States

The very important point when we handle centenarian and supercentenarian data sets is to bring into light the data from over 100 years of age that is data in the extreme right of the death distribution. These data mainly disappear in the right tail of the death distribution as is presented inside the red circle in the right hand side of Fig. 2.1.

The upper part A of Fig. 2.1 illustrates the distribution of female deaths in USA for the period 1990–1999. The data are provided by the Human Mortality Database (HMD). The main part of particular interest for the centenarian and supercentenarian case is located by a red circle. It includes the data sets from 100 to 110 years of age. However, as the data for 110 years include all the data from 110 years of age and higher, these figures are not used for the applications that follow. Instead the applications and projections done allocate the data form 110 years and higher to appropriate years of age based on the trend followed in the previous years from 100 to 109. The method used needs the transformation in logarithmic scale as presented in the following.

The middle part B of Fig. 2.1 illustrates the same data presented in the A part but in a logarithmic scale chart. The very important point here is that every level presented by the horizontal lines in the B part of the graph characterizes the number of persons dead at this age with the very important level one for the dead at the higher age level. The clear advantage is the presentation of the critical part included

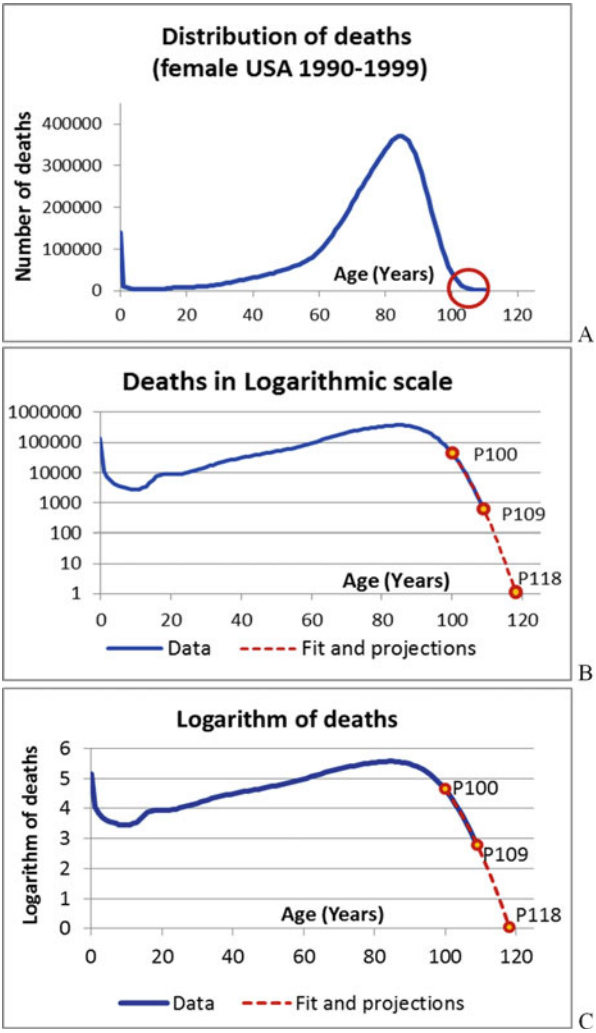


Fig. 2.1 (**a**) Distribution of deaths in USA (female, 1990–1999). (**b**) Deaths in logarithmic scale in USA (female, 1990–1999). (**c**) Logarithm of deaths in USA (female, 1990–1999)

into the circle of the part A of the figure in a convenient form for fitting a model and make projections until level one where the maximum reported age at death (MRAD) is found. For the case studied here this is at year 118 (P118 point in the graph).

The lower part C of Fig. 2.1 presents the logarithms of the death data. This is a simpler illustration with the MRAD of 118 years of age found at zero level on the X axis.

Several models could fit to the total curve expressing the number of deaths. However, for the last part to the right of the death curve a simple quadratic model for the logarithm of the number of deaths could be more appropriate. This is in accordance to the extreme value theory presented by Gumbel and others. The final part of the curve to the right, as it is expressed by the logarithm in Fig. 2.1c, is a smooth graph with a small curvature that could be modeled by a function of the form (where the quadratic term stands for the curvature).

$$\log(g(x)) = a(x - 100)^2 + b(x - 100) + c \tag{2.1}$$

We fit the above model to the 10 data points from 100 to 109 years of age. We estimate the parameters of this model by a nonlinear regression analysis algorithm and make the appropriate projections.

The parameters estimated are: $a = -0.005348$, $b = -0.15905$, $c = 4.651$, where, the quadratic parameter a stands for a negative curvature and the linear parameter b for a negative slope.

The appearance of super centenarians is related to the number of deaths as is illustrated in Table 2.1. The middle column includes the projections for the supercentenarians for the period studied (1990–1999). The MRAD is found at 118 years of age. Note that this number should come from the following relation $0.5 < \text{MRAD} < 1.5$. The 100 years projection is given in the third column of Table 2.1, by assuming that the death population follows the same pattern as for the period 1990–1999. In this case a MRAD equal to 121 years of age is expected in 2100, whereas a MRAD equal to 116 years of age should be found for 1 year death data selection (see the first column of Table 2.1).

These estimates could be correct for a continuing growth of the number of supercentenarians following the growth of the number of centenarians. However, the case of United States data in last decades do not support this argument as is illustrated in Fig. 2.2. Five 10 year periods from 1960 to 2009 are selected from the HMD and fit and projections are done.

It should be noted that by selecting 5 characteristic periods for the death distribution in USA (female), fit to the data from 90 to 109 years of age and doing projections an interesting MRAD point at 117 years is estimated for the 4 cases and one MRAD at 118 years of age, the latter resulting from the 1990–1999 period. The equation applied is analogous to the previous one:

Table 2.1 Supercentenarians estimated

	Average of 10 years	1990–1999	2000–2100
Age	1 year	10 years	100 years
110	34	335	3355
111	18	180	1796
112	9	94	938
113	5	48	478
114	2	24	238
115	1	12	115
116	1	5	55
117		3	25
118		1	11
119			5
120			2
121			1

$$\log(g(x)) = a(x-90)^2 + b(x-90) + c \quad (2.2)$$

These results for United States females are in favor of the argument for a stagnation of the MRAD development and for the maximum achieved MRAD during 1990–1999 period of time, here found at 118 years of age whereas, a MRAD at 117 years of age for the other periods studied is estimated.

The number of deaths of centenarians is increasing from 1950 and onwards though the growth is slower from 1995 to 2014 as it is expressed in Fig. 2.3. However, this growth could be compensated by the growing negative shift for the logarithm of deaths during time presented in Figs. 2.2 and 2.4. It looks out to be a

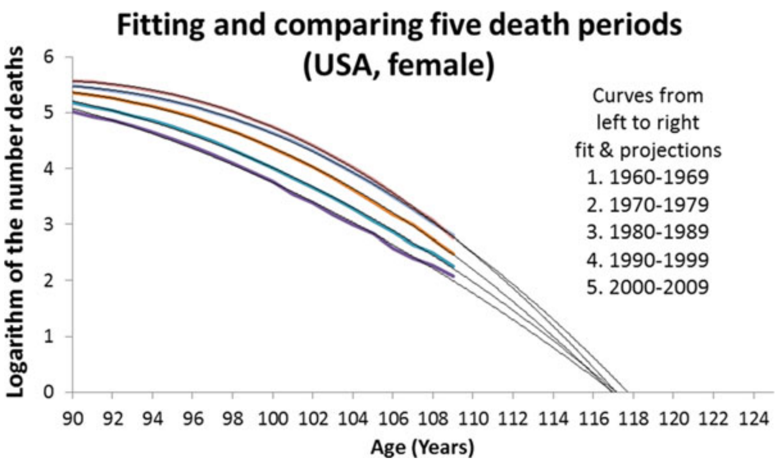


Fig. 2.2 Fitting and comparing five deaths periods in USA (female)

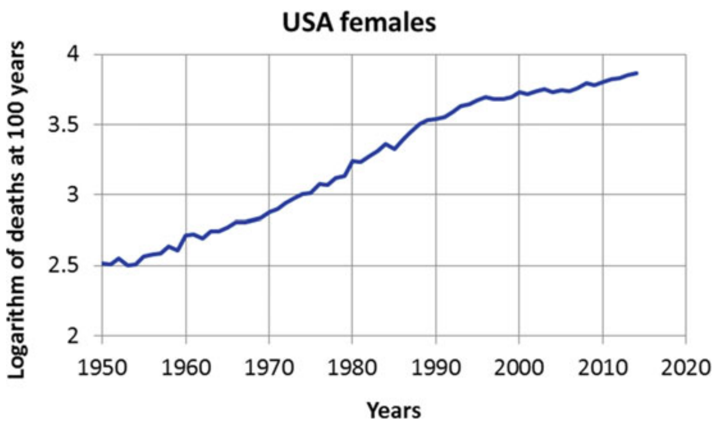


Fig. 2.3 Number of deaths of centenarians from 1950 to 2014 (USA, female)

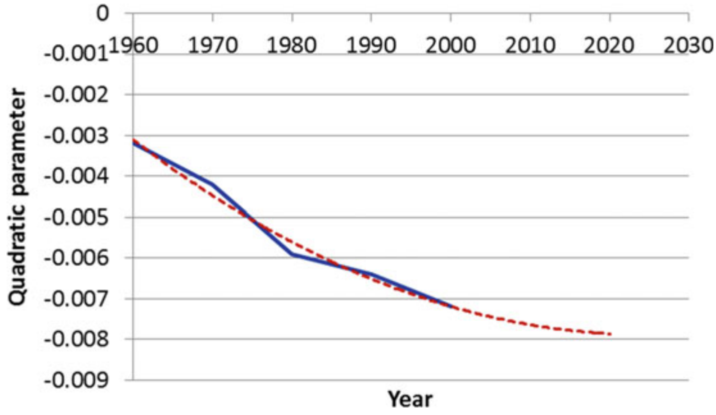


Fig. 2.4 Negative shift of parameter *a*

very hard work to define a possible stable behavior for the MRAD during time. This could lead to debates and conflicts looking at the high uncertainty of related projections.

However, the argument for a limit to the human life span should need similar stagnation trends for other countries of the world and especially for the large population countries. As far as centenarian death data are not available from China, India and Brazil, we can check the related data from France, Japan and United Kingdom provided by the HMD. These three countries and USA were the basis of the Dong et al. 2016 publication in Nature.

2.3 The Case of Japan

The Japan female deaths at 100 year of age steadily increase from 1950 and onwards as is illustrated in Fig. 2.5 (the number of deaths is expressed in logarithmic scale). This is a good result indicating a possible increase of the number of centenarians and supercentenarians (aged 100+ years of age) and thus increasing the probability of finding MRAD at higher ages. However, another indicator is needed to apply coming from the MRAD trend over time. As for the USA case presented in Fig. 2.2, five ten year time periods are selected and the model (2) is fitted to data. The MRAD for each case is found by estimating the year where the projections line crosses the X axis. The estimates for the 5 periods studied are 1970–1979 (MRAD = 109.8), 1980–1989 (MRAD = 111.3), 1990–1999 (MRAD = 112.4), 2000–2009 (MRAD = 115.3) and 2010–2014 (MRAD = 116.3). See also Fig. 2.6 where the period 2010–2014 stands for a 5 year period. The linear model MRAD = 0.1774*YEAR-240.53 is fitted to the 5 MRAD data points (see Fig. 2.7) with a fairly good $R^2 = 0.991$, and projections are done. Accordingly a

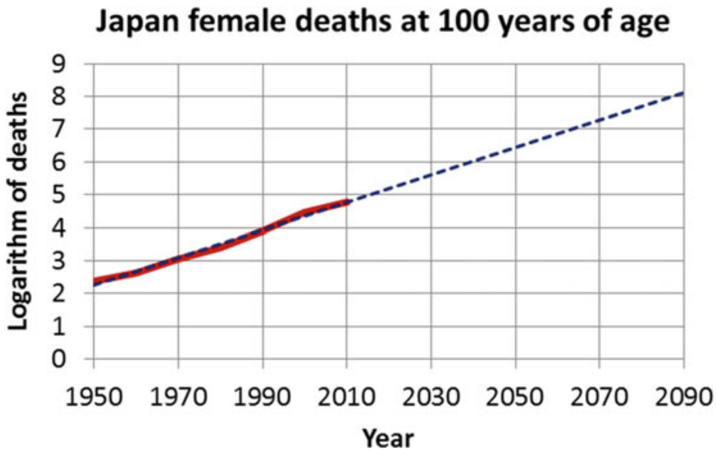


Fig. 2.5 Logarithm of Japan female deaths at 100 years of age

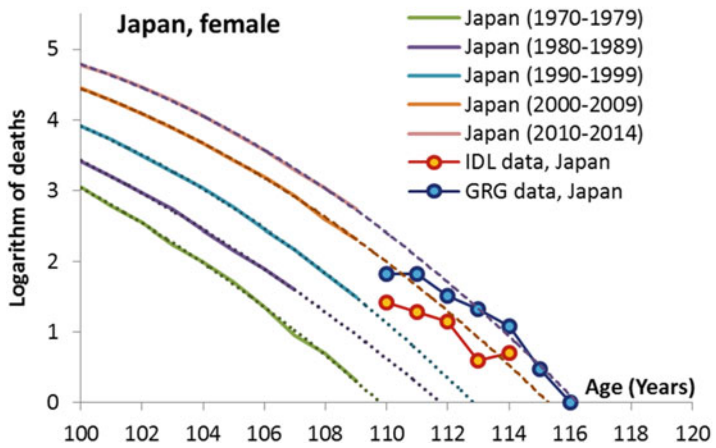


Fig. 2.6 Five year periods for the logarithm of deaths in Japan along with IDL and GRG data

MRAD at 118 years of age is expected by 2020, the 122 years of age should be reached by 2045 and a MRAD at 125 years of age is expected by 2060.

Figure 2.6 illustrates and the female supercentenarians for Japan as are provided by the IDL (1996–2005) and GRG (1998–2014) databases. For both databases (IDL and GRG) the cases collected cover two different time periods, 1996–2005 for the IDL database and a larger for the GRG database. For the latter the time period 1998–2014 was collected for our study. There is a 30 years period, 1966–1996, with only 11 supercentenarian in 205 cases. We have excluded these figures keeping the rest 194 instances from 1998–2014 for the study. This is clear from Fig. 2.8 that the first period 1966–1996 should be excluded. The IDL data points for the 1996–2005

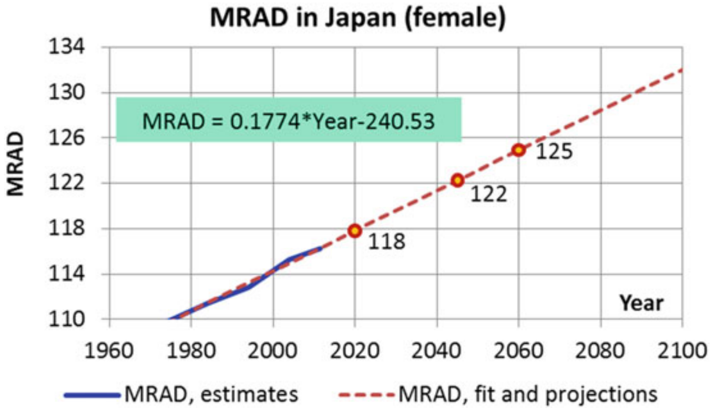


Fig. 2.7 Fit and projections for MRAD in Japan ($R^2 = 0.991$)

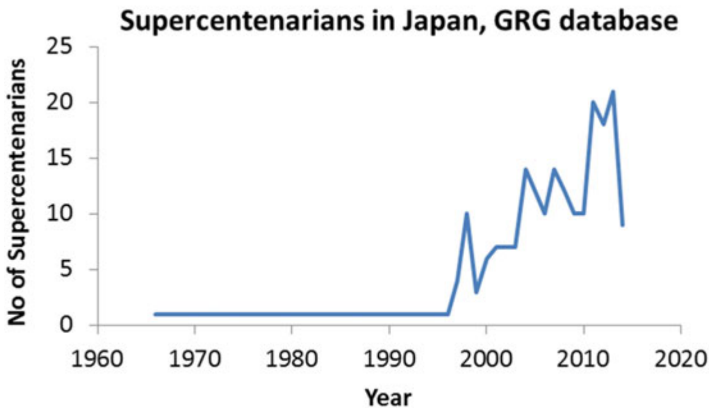


Fig. 2.8 Supercentenarians in Japan (GRG database)

period are located between the trajectories for (1990–1999) and (2000–2009) whereas, the GRG data points are close to the projected lines for the periods (2000–2009) and (2010–2014). Especially for the GRG data providing a MRAD at 116 years of age, the projected line for the period (2010–2014) fits perfectly to the same point for MRAD.

2.4 The Case of France

The France case has similarities with Japan application as the trajectories for the 10 year periods studied tend to keep a parallel like movement to the right hand side of the graph thus suggesting a growing process for the MRAD for the

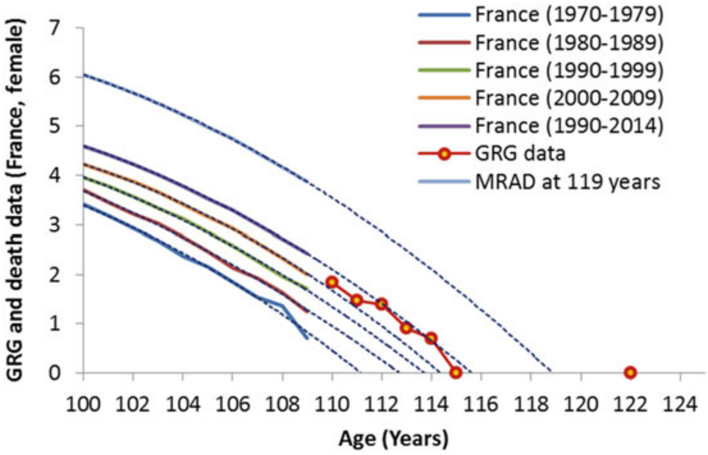


Fig. 2.9 France application for various time periods

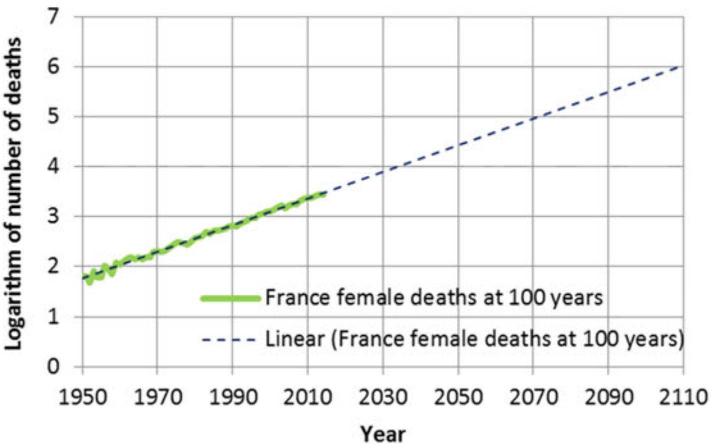


Fig. 2.10 Logarithm of France female deaths at 100 years of age (fit and predictions)

supercentenarians. The GRG data corresponding to the period 1990–2014 are close to the projections of the death data for this period (Fig. 2.9). That is far away from any short of prediction is the single point for the world record MRAD at 122 years. The trend for the deaths at 100 years of age in France steadily increases from 1950 and onwards in an exponential trend thus providing a linear trend for the logarithm of the number of deaths (see Fig. 2.10). The logarithm for the number of deaths in 2110 is 6, corresponding to 1.000.000 persons and to a MRAD at 119 years of age (see the related Fig. 2.9).

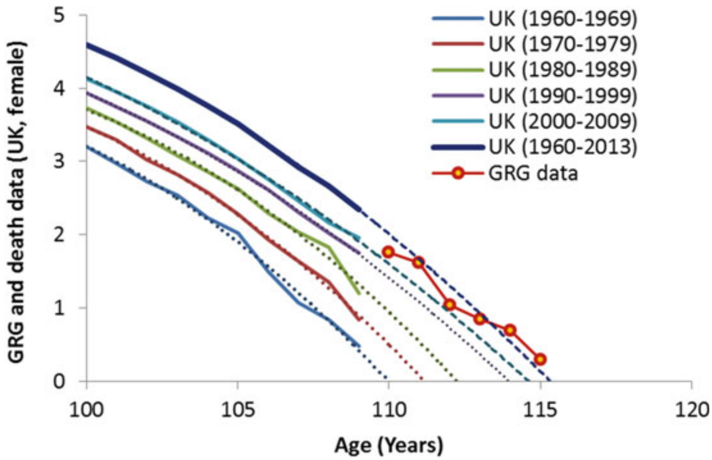


Fig. 2.11 Centenarian and supercentenarian fit and projections for UK (female)

2.5 The Case of United Kingdom

Similar to France and Japan is the growing process for the supercentenarians in UK presented in Fig. 2.11. Five female death periods from 1960 to 2009 of 10 years each are selected from the HMD. Model (1) is fitted to the data from 100 to 109 years of age and projections are done until crossing the X axis and define the MRAD. Very important for estimating the future trends for MRAD are the last two trajectories for the periods (1990–1999) and (2000–2009). In the case of UK both follow a parallel like trend defining an increasing process for MRAD.

2.6 Comparing France, United Kingdom and Japan

That it is demonstrated from these 3 countries (see Fig. 2.12) the number of centenarians is steadily growing while the supercentenarian trend is growing during time as well leading to higher MRAD.

2.7 The IDL Application

Supercentenarian female death data from 15 countries are downloaded from the IDL database as for 20 July 2017. Similar data are included in the Human Mortality Database (HMD) in the death tables for the years 100+ and presented as a single number for the deaths at 100 years of age and over. Though no further analysis is given in these death tables the information for the number of supercentenarians per

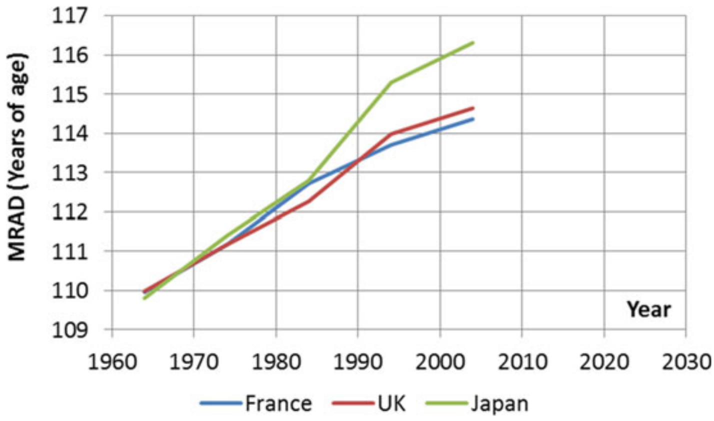


Fig. 2.12 France, UK and Japan comparisons for MRAD estimates

country at specific time periods (the yearly data are available) is vital for the calculations performed here. These death tables include all the age period from zero age to 109. The last 10 data points from 100 to 109 are used to estimate a trajectory for the future paths (projections) that define the supercentenarian trend per year of age from 110 years and onwards.

IDL and HMD-data include completely different number of data points for the supercentenarians as the IDL database covers the confirmed cases. Thus we have found 598 supercentenarians in the IDL database and 3066 in the HMD-data the latter providing more than five times (5.127) higher estimates. However, the HMD-data supercentenarian data are very important because we can arrange these data in the projection curve arising from the fit of a good model of the logarithmic form of Eq. (2.1).

This model fits to the 10 data points from 100 to 109 almost perfectly with a R2 = 0.99998. The projection presented in the Fig. 2.13 provides the MRAD at 119 years of age that is exactly the age of the second supercentenarian after Jeanne Calment. The next step is the find a trajectory appropriate for the IDL data in view that these data could follow a parallel like path than that provided from HMD-data for the same time period and for the same 15 countries selected. This is achieved very easily by moving the HMD-data trajectory in a lower position by dividing its element by an appropriate number so that to minimize the sum of squared errors. The new position is illustrated in the figure as HMD-data adapted to IDL. Now the trajectory for IDL provides a MRAD at 117 years of age. The IDL data points are illustrated with red circles and are fairly well adapted to the related trajectory with R2 = 0.9906. For both cases the outsider, the point at 122 years of age is far away from any estimate. It could be found with a probability 0.01 for the IDL case and 0.04 for the HMD-data case by means that we can find a MRAD for a population 100 times larger for the IDL case and 25 times larger for the HMD-data case. The trajectory adapted to 122 years of age is presented in Fig. 2.13. The estimation results are given in the next Table 2.2. Note that the MRAD will appear for a number 0.5 or

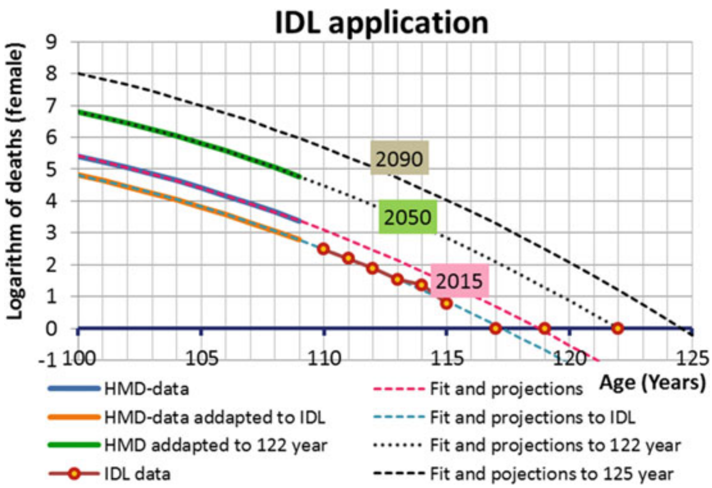


Fig. 2.13 Fit and projections for supercentenarians (IDL and HMD data bases)

Table 2.2 Supercentenarians estimated for IDL, HMD and HMD* databases (HMD* results from HMD-data adapted to a MRAD at 122 years of age)

Age	IDL	HMD	HMD*
110	308	1208	30,195
111	153	601	15,021
112	74	290	7257
113	35	136	3404
114	16	62	1551
115	7	27	686
116	3	12	295
117	**1**	5	123
118	**0.51**	2	50
119	0.20	**1**	20
120	0.08	0.30	7
121	0.03	0.11	3
122	0.01	0.04	**1**
Total	598	2345	58,613

higher by means that the logarithm should be approximately less than -0.3 thus shortening the population needed for at least one MRAD. For the case of 122 years of age the population needed is the half of that estimated to have exactly one in the estimates.

The related death female data for the periods selected are downloaded from the Human Mortality Database (HMD) and summarized as to form one unique database termed here as HMD-data. The periods for collecting the data per country are found from the explanatory details in the IDL database and are presented in parentheses as follows: Australia (1990–2004), Belgium (1990–2002), Canada (1962–2002), Switzerland (1993–2000), Germany (1994–2005), Denmark (1996–2000), Spain

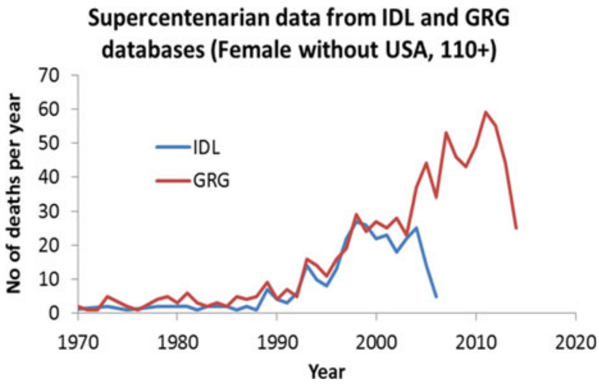


Fig. 2.14 IDL and GRG data series

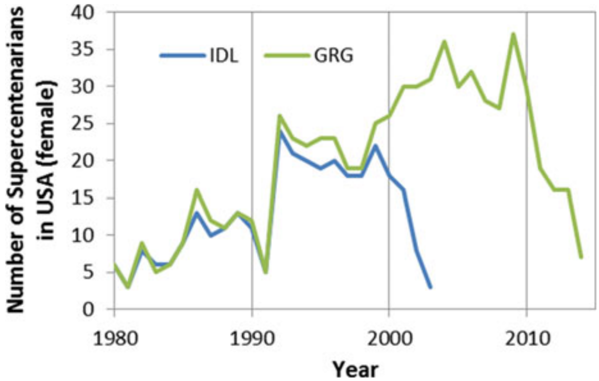


Fig. 2.15 Supercentenarians in USA (female). IDL and GRG data sets

(1989–2007), Finland (1989–2006), France (1987–2003), UK (1968–2006), Italy (1973–2003), Japan (1996–2005), Norway (1989–2004), Sweden (1986–2003) and USA (1980–2003).

Both IDL and GRG databases (see Figs. 2.14 and 2.15) are similar until 2003 and then the GRG database includes data until 2014.

Accordingly we use the IDL dataset for the applications that follow (see Fig. 2.16). The IDL data base provides the super-centenarian data until 2003.

The IDL group of countries without USA includes 13 countries for various periods of time. For the same periods we have downloaded the deaths from the Human Mortality Database and summarized all data to form a unique death distribution presented in Fig. 2.18 in continuous line. We fit the quadratic model to the data from 100 to 109 years of age and then a projection is done. The estimated MRAD is at 116.4 years of age. Similar are the results by applying the GRG data as well (see the dark circles in Fig. 2.17).

The application for USA (female) includes fit to the HMD death data in logarithmic scale, projections and comparisons with the GRG (Fig. 2.18a) and IDL

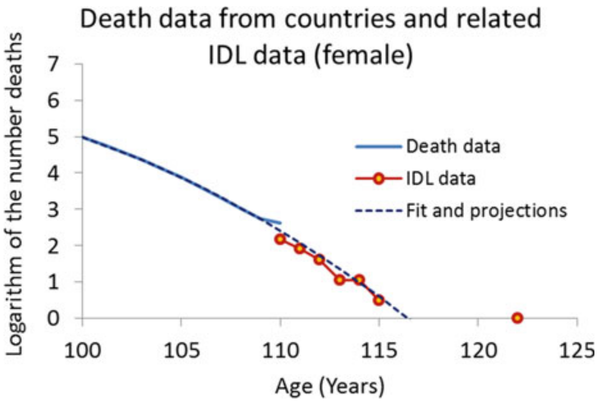


Fig. 2.16 Logarithm of deaths from selected countries, fit and projections, and IDL data

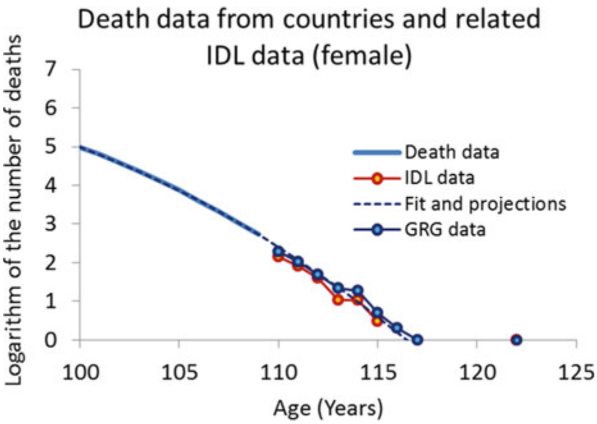
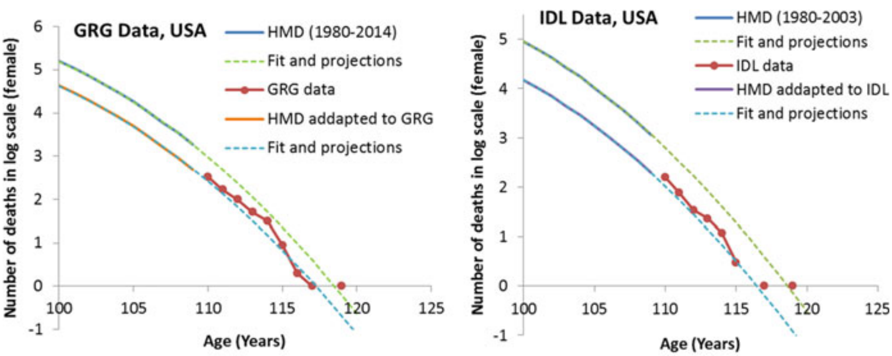


Fig. 2.17 HMD data for countries selected, fit and projections and IDL and GRG figures



A

R^2=0.955

B

R^2=0.904

Fig. 2.18 HMD data, fit and projections and GRG (**a**) and IDL (**b**) data sets for USA (female)

(Fig. 2.18b) data sets. The adaptation from GRG to HMD data base and IDL to HMD data base and vise-versa provide enough evidence for the use of both data bases in supercentenarian projection studies.

2.8 Summary

So far we have replied to the fundamental question regarding a limit to the human life span by providing methods and tools and make related applications.

While a stagnation appears for USA, the data for France and Japan clearly indicate a continuing growth for the level of supercentenarian trajectories and accordingly for the level of MRAD the latter growing with time.

The expected MRAD is closely related to the number of centenarians. The latter is growing fast in an exponential trend thus ensuring a quite large pull for the expected supercentenarians.

References

Brown, N. J. L., Albers, C. J., & Ritchie, S. J. (2017). Contesting the evidence for limited human lifespan. *Nature, 546*. https://doi.org/10.1038/nature22784.

De Beer, J., Bardoutsos, A., & Janssen, F. (2017). Maximum human lifespan may increase to 125 years. *Nature, 546*. https://doi.org/10.1038/nature22792.

Dong, X., Milholland, B., & Vijg, J. (2016). Evidence for a limit to human lifespan. *Nature, 538*, 257–259. ISSN: 1476-4687. https://doi.org/10.1038/nature19793.

Gompertz, B. (1825). On the nature of the function expressive of the law of human mortality, and on the mode of determining the value of life contingencies. *Philosophical Transactions of the Royal Society of London A, 115*, 513–585.

Hughes, B. G., & Hekimi, S. (2017). Many possible maximum lifespan trajectories. *Nature, 546*. https://doi.org/10.1038/nature22786.

Janssen, J., & Skiadas, C. H. (1995). Dynamic modelling of life-table data. *Applied Stochastic Models and Data Analysis, 11*(1), 35–49.

Lenart, A., & Vaupel, J. W. (2017). Questionable evidence for a limit to human lifespan. *Nature, 546*. https://doi.org/10.1038/nature22790.

Rozing, M. P., Kirkwood, T. B. L., & Westendorp, R. G. J. (2017). Is there evidence for a limit to human lifespan? *Nature, 546*. https://doi.org/10.1038/nature22788.

Skiadas, C. H., & Skiadas, C. (2010a). Comparing the Gompertz type models with a first passage time density model. In C. H. Skiadas (Ed.), *Advances in data analysis* (pp. 203–209). Boston: Springer/Birkhauser.

Skiadas, C., & Skiadas, C. H. (2010b). Development, simulation and application of first exit time densities to life table data. *Communications in Statistics-Theory and Methods, 39*, 444–451.

Skiadas, C. H., & Skiadas, C. (2014). The first exit time theory applied to life table data: The health state function of a population and other characteristics. *Communications in Statistics-Theory and Methods, 43*, 1985–1600.

Skiadas, C. H., & Skiadas, C. (2015). Exploring the state of a stochastic system via stochastic simulations: An interesting inversion problem and the health state function. *Methodology and Computing in Applied Probability, 17*, 973–982.

Skiadas, C. H., & Skiadas, C. (2017). *Exploring the health state of a population by dynamic modeling methods.* https://doi.org/10.1007/978-3-319-65142-2. (see at: https://link.springer.com/book/10.1007/978-3-319-65142-2).