Approaches and experiences in projecting mortality patterns for the oldest old

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1 The views and opinions expressed in this paper are those of the author and do not reflect those of the United Nations.

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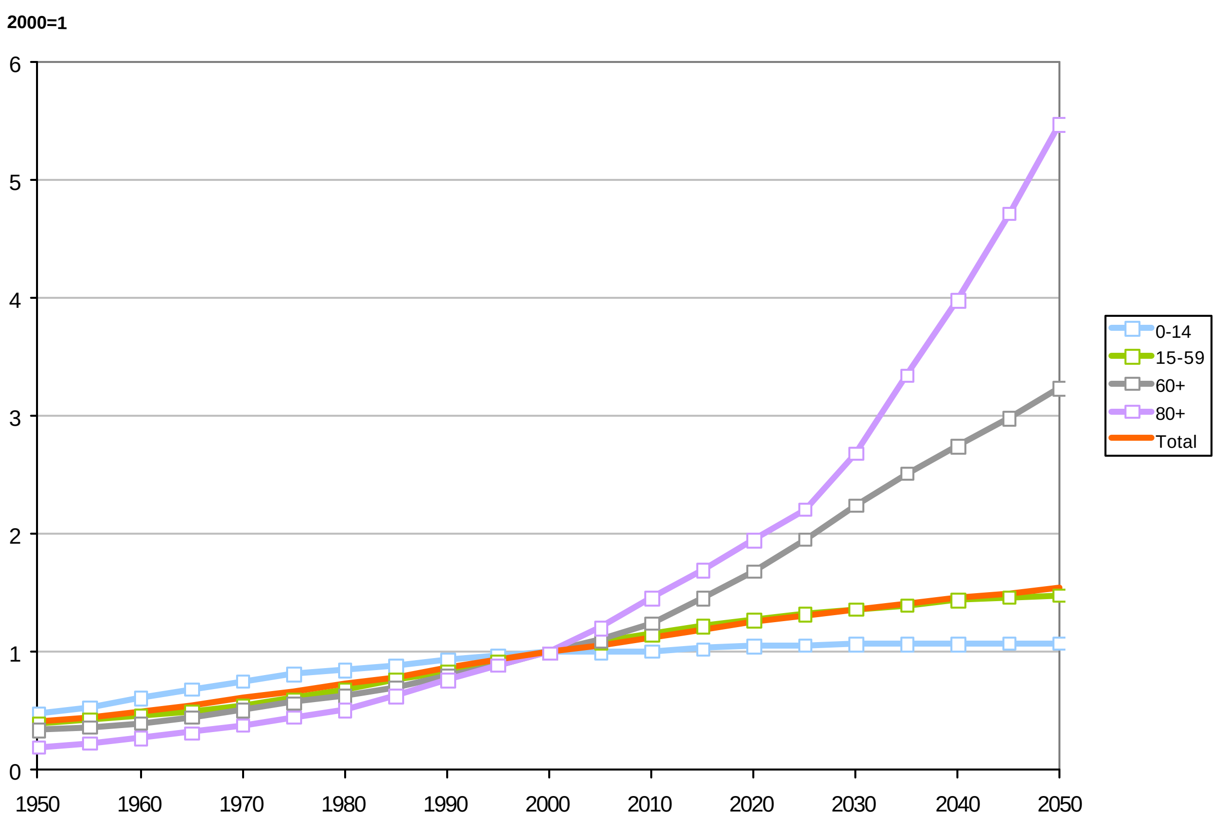
INTRODUCTION

It is estimated that in 2001, 72 million of the 6.1 billion inhabitants of the world are 80 years or older (United Nations, 2001). The population of the oldest-old (e.g. those 80 years and older) constitutes therefore 1.2 per cent of the world's population but, although it is a small fraction of the whole, it is the fastest growing segment of the population. Thus, whereas the world population is expected to increase by about 50 per cent and to reach 9.3 billion by 2050, the number of people aged 80 years or older is expected to increase more than five-fold, to reach 379 million in 2050 (Figure 1). Most of the growth of the oldest-old population will occur in the developing world where their numbers are expected to increase almost eight-fold, from 34 million in 2001 to 266 million in 2050. In the more developed countries, the number of oldest-old will likely triple, passing from 38 million to 113 million. By 2050, therefore, the majority of the oldest-old will be living in the less developed regions of the world.

Furthermore, because life expectancy continues to increase, not only are an increasing number of people surviving to very old ages but also deaths to the oldest-old are accounting for an increasing proportion of all deaths. Thus, at the global level, 18 out of every 100 deaths expected in 2000-2005 will be to persons aged 80 years or older (i.e., 10 million out of the expected 55 million deaths). In the more developed regions, the proportion of deaths to persons aged 80 or over is expected to be much higher— 42 per cent—and those proportions are expected to keep on rising.

Figure 1 **Growth of broad population age groups, world total 1950-2050.**



In view of such trends, it is important to have detailed information about the age structure of the oldest-old and about the population dynamics to which they are subject, namely, the risks of dying by age. However, until 1996, the estimates and projections of population produced by the United Nations Population Division did not provide an age breakdown for the group aged 80 years or older. In order to provide such information, it is necessary both to obtain data on the age distribution of the population classified by five-year age groups above age 80 and estimates of the mortality risks to which the population in those age groups is subject. Unfortunately, such data are not readily available for most countries. Developing countries, in particular, generally lack the necessary information either because reliable statistics on adult mortality in general and on old-age mortality in particular do not exist or because the available statistics on old-age mortality are unreliable, being biased by poor age reporting both regarding those alive and those who die (Condran et al. 1991; Kannisto et al, 1994). In a review of data availability, Hill (1997) concluded that the coverage of death registration had not improved between the early 1970s and the early 1990s. While the proportion of developing countries lacking information on adult deaths by age group remained constant at 44 percent, their share of the world population rose from 66 per cent in the early 1970s to 69 percent in the 1990s. Furthermore, when it comes to both population age distributions and mortality rates among the very old, problems of data reliability are not confined to the developing world. Even in countries with advanced statistical systems inconsistencies of age reporting between the ages of the living and those who die can bias the estimated rates of death for the oldest-old.

Therefore, to produce both estimates and projections of population with an open-ended interval of 100 years and over instead of the then more traditional 80 years and over, the Population Division had to resort to models that could be adapted to the varied situations of the 187 countries whose populations are projected using the components method. This paper describes the methodology adopted by the Population Division for that purpose. It describes first the use of a relational mortality model with a standard proposed by Himes, Preston and Condran to extend life tables beyond age 80. It focuses later on the projection of mortality using the method proposed by Lee and Carter. After a description of each method, an assessment of their performance and robustness is undertaken. A final section adds some observations regarding possible future trends in survival among the oldest-old and necessary improvements of empirical data.

1. EXTENDING LIFE TABLES TO AGE 100 AND BEYOND

In 1997 the Population Division convened a meeting of a Working Group on Projecting Old-Age Mortality and its Consequences to review the different options to extend age-specific mortality rates to older ages (Population Division, 1997). Three approaches were examined in some detail, namely:

- The old-age mortality standard developed by Himes, Preston and Condran (1994).
- The old-age term of the Heligman-Pollard mortality model (Heligman and Pollard, 1980).
- The Coale-Kisker method of closure of life tables (Coale and Kisker, 1990).

The Working Group recommended the use of a relational mortality model based on the old-age mortality standard developed by Himes, Preston and Condran (HPC standard) mainly because that standard was derived from the observed old-age mortality patterns of a variety of populations with reliable data. However, because empirical data do not reflect as yet the very low mortality levels projected in the future and mortality rates at very advanced ages are affected by random variation, it was later decided to replace the HPC standard at ages 95 and over with mortality rates derived using the old-age term proposed by Heligman and Pollard. Furthermore, in order to avoid random mortality crossovers between different model life tables at very advanced ages, the Coale-Kisker method was used to close the life tables.

1.1. THE HIMES-PRESTON-CONDRAN MORTALITY STANDARD

Himes, Preston and Condran proposed in 1994 a standard mortality schedule (HPC standard) representing the typical mortality pattern at advanced ages based on the patterns observed in a variety a countries and periods. The HPC standard was constructed by examining mortality rates by single years of age for the age range 45 to 99 from 16 low mortality countries[2]. The mortality experience covered spanned the period 1948-1985. Observed mortality data were subject to strict reliability and consistency tests to be included. In the end, the standard was derived from 82 different mortality schedules for each sex.

Figures 3 and 4 show the HPC standard by sex as published in 1994. Two deficiencies are noticeable. First, the standard exhibits visible fluctuations above age 90 for both sexes and around ages 54 and 81 for males. Second,

[2] The 16 countries are: Australia, Austria, Belgium, Canada, Denmark, England and Wales, Finland, Hungary, Italy, Japan, The Netherlands, New Zealand, Norway, Scotland, Spain and Sweden. Czechoslovakia, Ireland and Northern Ireland were excluded because of insufficient data quality. Data from France, East and West Germany and the United States were not included due to data inconsistencies.

the standard does not cover age-specific mortality patterns above age 99. It was therefore necessary to remove fluctuations by smoothing the standard and to extend it beyond age 99.

The empirical mortality standard was smoothed by a moving average of the form:

$$g_x = \frac{m_{x-1} + m_x + m_{x+1}}{3}$$

$$h_x = \frac{g_{x-1} + g_x + g_{x+1}}{3} = \frac{m_{x-2} + 2m_{x-1} + 3m_x + 2m_{x+1} + m_{x+2}}{9}$$

where m_x is the central mortality rate at age x, and h_x is the resulting smoothed value for age x.

Figure 2 Original HPC mortality standard, m(x)

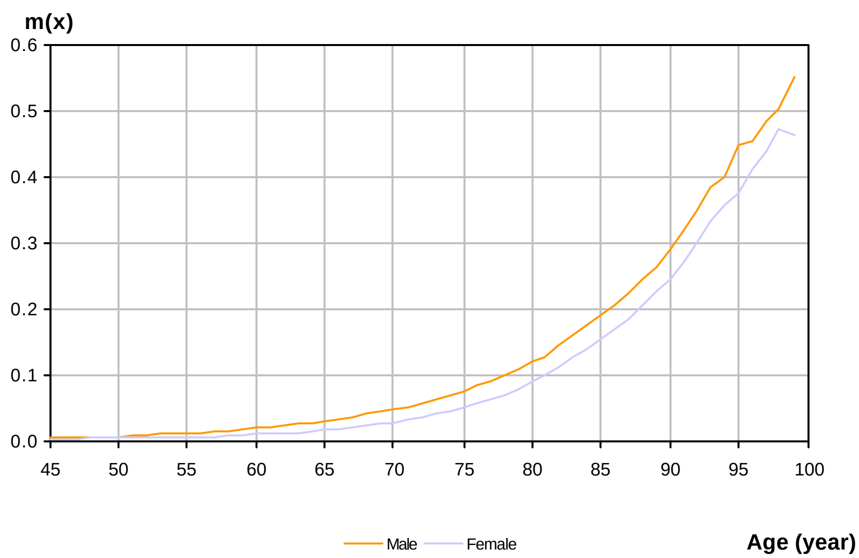
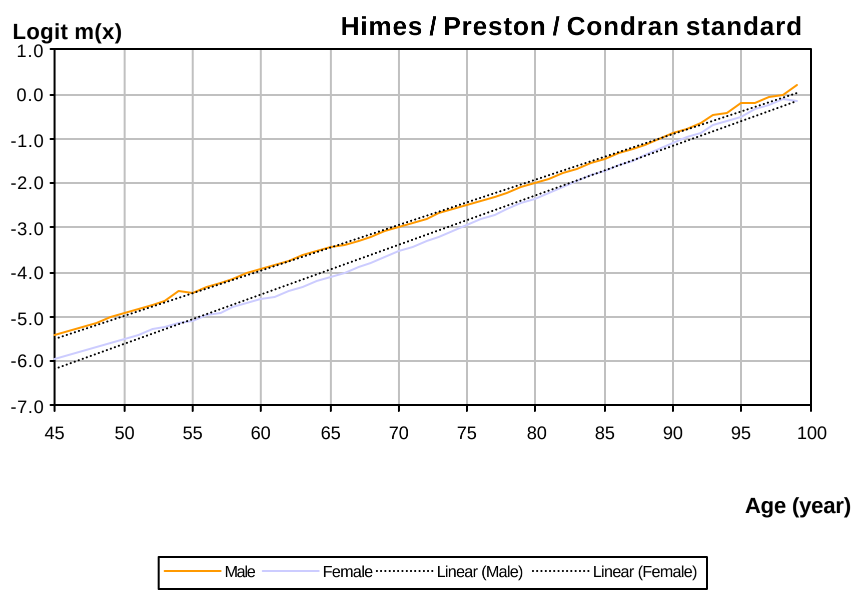


Figure 3 Logit transformation of the original HPC mortality standard and fitted linear trend



Himes, Preston and Condran had themselves suggested that the standard they proposed could be extended from age 95 to 115 by extrapolating it linearly in the logit domain. It can be shown that such a linear extension in the logit domain is equivalent to the old-age term of the Heligman-Pollard model. The linear function in the logit domain is:

$$Logit(m_x) = a + bx \qquad (1)$$

where the logit is defined as:

$$Logit[f(x)]) = F(x) = \ln\left(\frac{f(x)}{1 - f(x)}\right) \qquad (2)$$

$$f(x) = \frac{e^{F(x)}}{1 + e^{F(x)}} \qquad (3)$$

By substituting (1) into (3), one obtains the old-age term of the Heligman-Pollard model:

$$f(x) = \frac{e^{a+bx}}{1 + e^{a+bx}} = \frac{e^{a}e^{bx}}{1 + e^{a}e^{bx}} = \frac{GH^x}{1 + GH^x} \qquad (4)$$

where parameters G and H are:

$$G = e^a$$

$$H = e^b$$

The smoothed and extended HPC standard, covering the age range 45 to 115 years, is presented in Annex table 1. Once the HPC standard had been extended to advanced ages, the procedure used to extend any other set of m_x values made use of the empirical fact that mortality patterns, appropriately transformed, are often linearly related. In this case, the logit function was used as the linearizing transformation. That is, the logit transformation of the given set of m_x values would be linearly related to the logit transformation of the standard set of m_x value. Fitting a line to those pairs of values would provide the á and â values (i.e. the regression coefficients) that would permit the estimation of the m_x values at advanced ages from those of the standard.

1.2. THE COALE-KISKER METHOD

Coale and Guo (1989) used a novel method to close a life table that assumes that the exponential rate of mortality increase at very old ages is not constant, as in the classical Gompertz model, but declines linearly. This feature of mortality at very advanced ages has been empirically verified by a number of studies (Horiuchi and Wilmoth, 1997a and 1997b). Coale and Guo applied this approach to close the extended version of the Coale-Demeny model life tables presented in five-year age groups. Later, Coale and Kisker (1990) used the same approach to close empirical life tables by single years of age. Following common practice, the method first used by Coale and Guo and then by Coale and Kisker is henceforth referred to as the Coale-Kisker method.

The Coale-Kisker method has two parameters, namely the Gompertz parameter k and a mortality rate for the uppermost age, say 110 years. Coale and Kisker set a value of 1.0 per 1,000 for m_{110} for males, and 0.8 per 1,000 for females[3]. The mortality differential by sex at age 110 was explicitly chosen to avoid a crossover between male and female mortality at very advanced ages.

Having set mortality at age 110, the Gompertz parameter is calculated from the given age-specific mortality rates m_x as follow:

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3 Wilmoth (1995) later extended the original Coale/Kisker method by transforming it into a regression model that can be used to estimate empirically the age specific mortality rate at m110, for instance.

$$k_x = Ln\left(\frac{m_x}{m_{x-1}}\right) = Ln(m_x) - Ln(m_{x-1})$$

or, setting x=85,

$$k_{85} = Ln\left(\frac{m_{85}}{m_{84}}\right) = Ln(m_{85}) - Ln(m_{84})$$

$$m_x = m_{84} * \exp\left[\sum_{y=85}^{x} k_y\right], \ for\, x = 85, 86, ...$$

If k_x were constant (e.g. $k_x = k$), then this equation becomes the classic Gompertz:

$$m_x = m_{84} * \exp\left[(x-85) * k\right]$$

Coale/Kisker assume that k_x is linear above a certain age, 85 years in this case, that is:

$$k_x = k_{85} + s * (x-85)$$

Solving for s yields:

$$s = -\frac{\left[Ln\left(\frac{m_{84}}{m_{110}}\right) + 26k_{85}\right]}{325}$$

Age-specific mortality rates are then calculated using one of the two following formulae:

$$m_x = m_{84} * \exp\left[\sum_{y=85}^{x}\left(k_{85} + (y-85) * s\right)\right], \ \ for \ \ x = 85, 86, \ ...$$

or, without the need to accumulate the k's and the s's:

$$m_x = m_{x-1} * \exp\left[k_{85} + (x-85) * s\right], \ \ for \ \ x = 85, 86, ...$$

1.3. DISCUSSION

Truncated mortality patterns are traditionally extended using a variety of approaches, be they an extension based on a mathematical function or a relational model using a given standard. No method, however, can guarantee best results in all circumstances. In the case of mathematical functions, the results will be satisfactory to the extent that the actual force of mortality conforms to the functional form used. In the case of a relational model based on a standard, the results depend on the extent to which the logit transformation of the standard is actually linearly related to the logit transformation of the mortality schedule under consideration. Clearly, when extrapolated measures of mortality are obtained for age ranges over which there is virtually no reliable data available, it is not possible to assess the goodness of fit of the results obtained. The best one can do is test whether the fit at lower ages, where reliable data exist, is acceptable. Furthermore, there is uncertainty about which age range should be used as a basis for extrapolation, especially when such extrapolation is being carried out by assuming a linear relationship with the suitably transformed standard. To illustrate this point, the HPC mortality standard was fitted using several age ranges to the empirically observed age patterns of mortality of Sweden and France. Figures 5 and 6 show the fitted values resulting from the use of six different age ranges, starting with 45-79 and ending with 70-79. The resulting variability of mortality patterns at very old ages is modest for Swedish males (figure 5), but substantive for French males (figure 6). In general, worse fits are obtained when relatively young age groups are included in the fitting range (i.e. ages 45 to 60). When using this extension procedure in the preparation of estimates and projections at the Population Division, the standard was fitted using a weighted least square procedure that gives more weight to older age groups. In addition, the fitting algorithm iterates to a best fit by successively dropping younger age groups from the fitting range.

Figure 4 **Male age specific mortality rates for Sweden, 1991-1995, and results of several HPC extensions.**

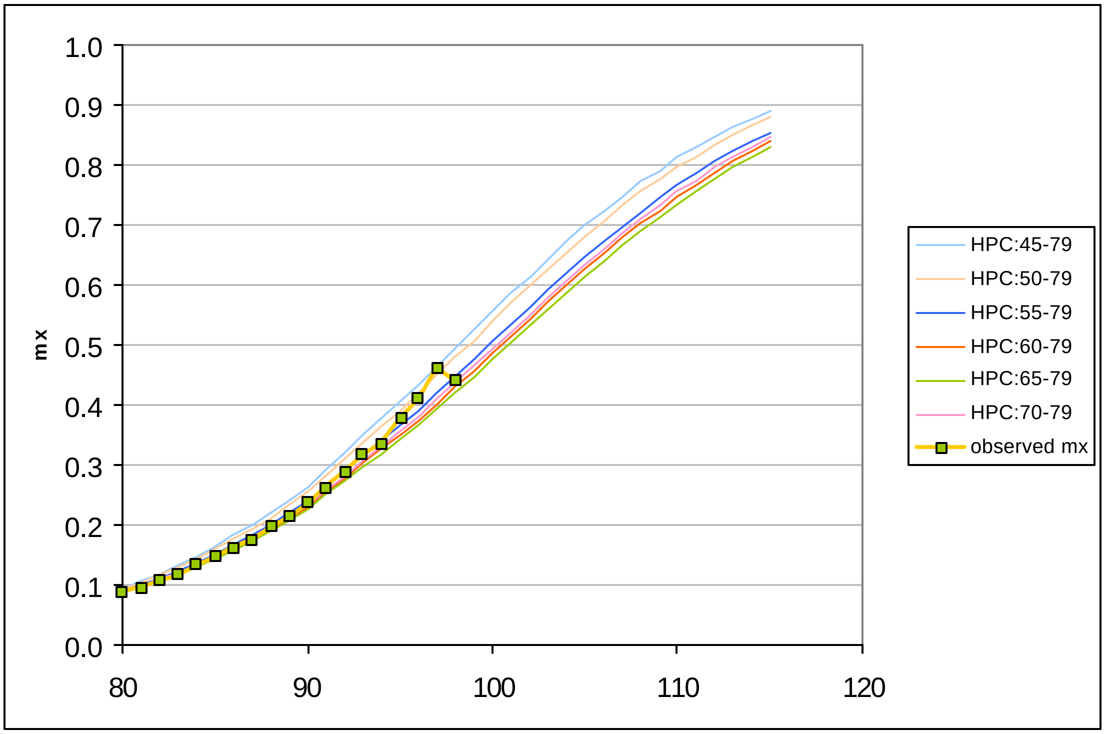
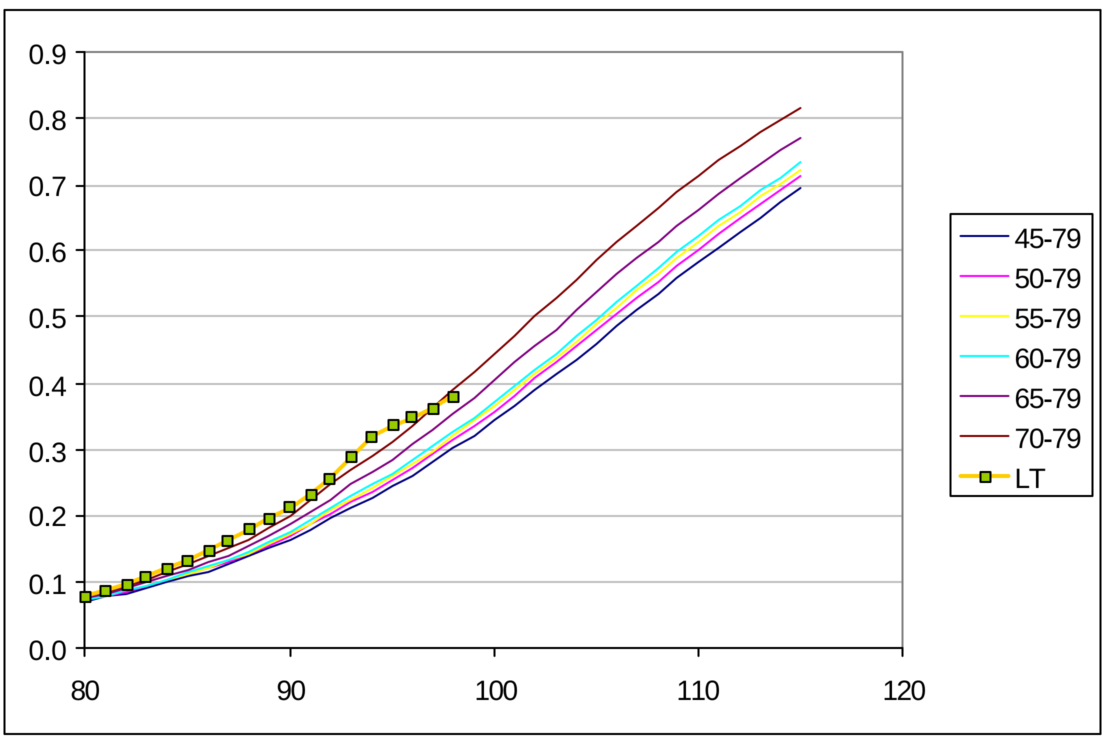


Figure 5 **Male age specific mortality rates for France, 1992-1994, and results of several HPC extensions.**



The HPC standard was also used to extend the model life tables used by the Population Division in preparing population projections, namely the Coale-Demeny Regional Model Life Tables (Coale, Demeny and Vaughn, 1983; Coale and Guo, 1989) and the UN Model Life Tables for Developing Countries (United Nations, 1982). However, these life tables were not compatible regarding their treatment of very old age groups. The UN model life tables were originally closed by applying a Makeham-type function, and provided data only for ages up to age 85. The Coale-Demeny model life tables as revised in 1983 had been extended to 100 years of age using a Gompertzian function (Coale, Demeny and Vaughn, 1983), while the life tables for higher life expectancy added to this system by Coale and Guo (1989) used a non-Gompertzian closing method that is similar to the Coale/Kisker method discussed in this paper. Although the different closing methods had little impact on life expectancy at age 80, they can result in marked differences in the number of survivors to very high ages. Consequently, it was important to ensure that all model life tables used were closed by the same procedure. The Coale-Kisker method was used for this purpose because use of the relational model with the HPC standard resulted in inconsistencies at very advanced ages, that is, age-specific mortality rates above age 100 belonging to model life tables with contiguous life expectancies would cross over because of instability in the numerical fitting procedures. Use of the Coale-Kisker method of closure avoided that problem by allowing the analyst to set the mortality rates of the uppermost age in a way consistent with the overall order of life expectancy at birth. Once that uppermost mortality rate was set, the trajectories of age-specific mortality rates for advanced ages also ordered themselves properly.

2. PROJECTING MORTALITY PATTERNS AT VERY OLD AGES USING THE LEE-CARTER MODEL

To project mortality, the Population Division uses a two-step process. First, recent trends in overall life expectancy are established on the basis of national estimates, adjusted as necessary. When data on adult mortality do not exist or are severely deficient, life expectancy if established on the basis of estimates of mortality in childhood and an assumed model pattern of mortality. Assumptions about future trends in life expectancy are made on the basis of a set of models that ensuring international consistency (United Nations, 2000, p. 188)

Age-specific mortality for the projection period is calculated in a second step. In the absence of actual age-specific mortality data, mortality patterns are obtained from a model specified by the analyst. A choice can be made among nine different families of model life tables, the five in the United Nations models for developing countries, and the four in the Coale-Demeny set. If information on the actual age-specific mortality pattern of a population is available, that pattern is modified over the projection period until it eventually converges to the pattern of a model selected by the analyst. In this process, the first step is to extend the actual age-specific mortality rates for the range 80 years and over.

In some cases, the analyst may choose to provide the age-specific pattern of mortality that is to be used for each five-year period of the projection span. In such a case, the eventual convergence to a model mortality pattern does not take place but it is still necessary to extend the age-specific mortality data provided by the analyst to the range 80 and over.

Until 1996, the model life tables used by the Population Division had life expectancies whose upper limits were 82.5 years for males and 87.5 for females (United Nations, 1988). However, as the projections were extended to 2050 and mortality continued to decline to very low levels in some developed countries, a higher upper limit became necessary. Currently, the model life tables have life expectancies going up to 92.5 years for both males and females. This extension of the life expectancy range covered by the model life tables shed light on the types of projection procedures that could be used for age-specific mortality and allowed an improvement of the methodology used by the Population Division.

In order to generate internally consistent sets of model life tables for levels of life expectancy not yet observed, a projection method developed by Lee and Carter (Lee and Carter 1992) was used. This method has been successfully employed to project mortality for a number of countries, including the United States (Lee and Carter, 1992), Japan (Wilmoth 1993), Chile (Lee and Rofman 1994) and Australia (Booth, 2001).

The original Lee-Carter procedure projects past patterns of age-specific mortality change into the future using time series methods. The evolution of age-specific mortality rates is modeled as exponential rates of change of a normalized, or average, mortality pattern. The model has the form:

$$f_{xt} = \ln(m_{xt}) = a_x + b_x k_t + e_{xt} ,$$

with the parameters:

a_x standard age-pattern of mortality, expressed as the average of the logarithm of the mortality rate $m_{x,t}$ at age x over time t.

b_x age-specific pattern of mortality change

k_t time trend.

ε_{xt} error term.

It has been established empirically that the time-dependent term (k_t) is often linear over most parts of the observation period. This is a useful feature since it allows for a relatively easy interpretation and projection. But even in cases were two or more distinct phases of the transition to lower mortality have been observed over longer periods of time, k_t has been found linear in those periods (Wilmoth 1993; Booth, Maindonald, and Smith 2001).

Inverting the logarithmic function, Wilmoth (1993) noted that the model can be written as:

$$m_{xt} = A_x B_x^{K_t}$$
$$A_x = e^{a_x}, B_x = e^{b_x}$$

According to this formulation, if k_t changes linearly over time, then each age-specific mortality rate changes at a constant exponential rate (Carter and Lee 1992, p. 396).

Projections are carried out by projecting the only time-dependent parameter k_t using appropriate statistical techniques. Lee and Carter used a random walk approach, which allowed for the calculation of confidence intervals for projected life expectancies.

In order to use the Lee-Carter approach to project mortality patterns on the basis of model life tables, some transformations are in order since the families of model life tables available are organized as collections of life tables at distinct levels of life expectancy of birth but do not contain a time reference. Therefore, the model's time index needs to be replaced with an index reflecting level of life expectancy. Hence the model becomes:

$$f_{xl} = \ln(m_{xl}) = a_x + b_x k_l + e_{xl} ,$$

where the index l represents the level of life expectancy associated with the corresponding age-specific mortality rates (m_x) and the parameter k_l represents the trend in the level of life expectancy at birth (in years).

The transformed Lee-Carter model was tested using the families of the Coale-Demeny model life table system. The model was fitted to series of model life tables spanning levels of life expectancy from 20 years to 75 years, and then projected to a life expectancy of 92.5 years. The results were, at first sight, generally encouraging. The method produced a set of smooth and consistent age patterns of mortality that would pass a visual inspection. However, in contrast to the original model, where the time trend (k_t) conveniently is roughly linear, the trend parameter (k_l), representing levels of life expectancy, takes here the form of a convex function, declining faster as life expectancy reaches higher levels. Such a trend is not surprising, since it reflects the empirical observation that similar gains in life expectancy tend to take longer the higher the life expectancy. The original Lee-Carter model, formulated in the time domain, produces results that conform to this finding when k_t is extrapolated linearly.

Although the results looked good when analyzed graphically, the projected age-patterns of mortality differed noticeably from recent evidence, as embodied, for example, in the revised model life tables prepared by Coale and Guo (1989) and in the two ultimate life tables prepared by the Population Division (United Nations, 1988) and the US Bureau of the Census (Arriaga, 1994). Apparently, therefore, the patterns of change embodied by the existing families of model life tables are not well suited to infer future trends in the evolution of age-specific mortality patterns. Indeed, Coale and Guo (1989) decided to revise the original Coale-Demeny life tables for that reason. The original model life tables contained tables for levels of life expectancy for which no empirical evidence had been available at the time of preparation (with life expectancies 75 years or higher) and which had been obtained by extrapolation. These extrapolated life tables consistently underestimated mortality rates at young ages and overestimated mortality for older persons as comparison with actual mortality patterns for low-mortality countries revealed. Coale and Guo did not comment on why the earlier attempt to extrapolate age-patterns of mortality failed. One possible reason is that the original Coale-Demeny model life table system is based on national life tables that cover approximately 100 years of mortality experience, more than half of which are from periods before 1945, and none of them is based on periods after the 1960s. Therefore they had no basis for reflecting the impact of changes in cause-of-death composition, public health interventions and changes in life styles that occurred later. The findings of Wilmoth (1993) and Booth (2001) regarding the long-term evolution of mortality in Japan and Australia also indicated that k_t does not necessarily follow a linear trend and suggests that past experience is not necessarily the best predictor of the future.

Regardless of the adequacy of the data used, it was also found that the Lee-Carter model exhibited a general tendency to produce extremely low mortality rates for younger age groups when used to project life tables for high levels of life expectancy. Although the model effectively prevents age-specific mortality from becoming negative since it is modeled in the logarithmic scale, the rates can nevertheless become virtually zero. In other words, the model gradually ‘forgets’ the reference age-pattern of mortality as it approaches lower mortality. The very low projected mortality rates for children are not of direct relevance for mortality at advanced ages. However, the possibility of introducing lower bounds by age group might be considered to enhance its performance.

A variation of the Lee-Carter method that uses such lower bounds was developed. Let’s assume that there are some intrinsic lower limits of mortality by age. The Lee-Carter model can incorporate such lower bounds by restricting the modeling to that part of mortality by age that is subject to change. To do this, one can subtract the lower bounds of mortality from the empirical mortality rates, and fit the model on the remainder. After the model is fitted, and mortality patterns of the remaining mortality are projected, the lower bounds are added back. This procedure is equivalent to an age-specific Makeham correction.

The extended Lee-Carter model with lower bounds incorporates the following as specific instances:

1. The original Lee-Carter model if the lower mortality bounds are set to zero.
2. The Makeham correction if the lower bounds are set to a fixed value for all age groups (Gavrilov and Gavrilova, 1991).
3. The age-specific Makeham correction when the lower mortality bound is made equal to a limiting life table. This approach assumes that there is an age-specific intrinsic mortality that cannot be reduced.

For the purpose of extending the various model life tables to very high levels of life expectancy, a constrained version of the Lee-Carter model was used. Thus, it was used to interpolate geometrically between a reference model life table with a life expectancy of 75 years and an ultimate life table with very low mortality that reflected likely mortality patterns based on current experience (United Nations, 1988, see tables 2 and 3). Model life tables with life expectancies ranging from that of the reference table and that of the ultimate life table were obtained by iteratively modifying the level parameter of the Lee-Carter model (k_l) until the desired life expectancy was reached. For levels of life expectancy higher than that of the ultimate life table, the pattern of change between the reference table and the ultimate life table estimated by the Lee-Carter procedure was extrapolated.

Concerned with the numerical stability of mortality projections at very old ages, limit life tables (Duchene and Wunsch, 1988a and 1988b) were tested, as suggested in option three of the amended Lee-Carter model. However, it was found that such a provision is not required in order to assure reasonable projections results. Moreover, since such limit life tables are highly speculative, it was decided to implement only a simple Makeham correction, with a lower bound of m_x set to 0.00002 for all age groups except the first one, where it was set to 0.00023 for males and 0.00038 females (Duchene and Wunsch, 1988a and 1988b). The resulting life tables for a life expectancy of 92.5 years for the North Model of the Coale-Demeny system of model life tables and for the General Pattern of the UN system of model life tables are presented in the annex.

3. CONCLUSIONS

In the past, mortality has exhibited distinct regional patterns, in both their shapes and their patterns of change over time. For this reason, several families of model life tables have been constructed and successfully used. The question arises whether patterns of mortality and mortality change in the future will ultimately converge to one or very few characteristic patterns, or whether a substantial variety will persist. Current projection practices favour convergence (United Nations, 1988). Coale and Guo (1989) suggested that mortality patterns worldwide might converge to a pattern similar to the North model of the Coale-Demeny system. Convergence to very similar patterns seems more likely for age-specific mortality rates that are increasingly moving toward the lowest levels possible, such as those relative to childhood or adolescence. Theories of natural limits to survival would lend some support to this assumption. However, the same argument cannot be made about mortality at older ages, which is far from reaching a lower limit, and whose patterns may end up being fairly diverse even at comparable levels of life expectancy.

There are today two alternative views about the future evolution of mortality at older ages: compression vs. expansion (sometimes also called rectangularization vs. steady progress). Mortality compression would occur if age-specific mortality were to continue declining over a widening range of adult ages, but would meet natural limits for very advanced ages (Bourgeois-Pichat 1978; Fries, 1980; Gavrilov and Gavrilova 1991). As a result, the survivor curve would approach a rectangle and mortality across countries may indeed converge to similar patterns. The modified Lee-Carter projection model for age-specific mortality patterns would operate under such hypothesis when setting the mortality bounds to these limits. In the case of steady progress, there would be no 'natural' limits to further reductions in mortality at higher ages, or the age at which natural limits set in could move upward (Olshansky et al 1998). Consequently, all age groups, especially at higher age groups, would continue to experience declining mortality. The age pattern of mortality would not change substantially but the age range would expand (Manton, Stallard and Tolley, 1991; Manton 1992, Vaupel and Lundstrom 1994; Olshansky 1998). In this case, the Lee-Carter model could be used without specification of age-specific lower bounds. More research is needed to verify these models of change.

Lastly, although detailed data on old age mortality are collected in most countries of the developed world, they are not so commonly available for developing countries. Furthermore, even in developed countries, the quality of age reporting deteriorates among the very old. National statistical offices do not evaluate regularly the quality of these data and it is not evident how to correct any biases that might be detected. The consistent evaluation of the quality of data on the elderly and a wide dissemination of the findings of such evaluations are needed. Indicators of data quality for these data need to expand on those suggested by UN recommendations[4]. In addition, it is crucial to add detailed documentation on the techniques used to construct life tables to the publications in which those data are disseminated. It is also important to ensure that data on the oldest-old are published with sufficient detail. Use of 100+ as the open ended age group should be standard in the preparation of tabulations of population and deaths by age and sex. With the number of persons in advanced ages growing so rapidly in modern populations, detailed demographic characteristics of this group should become part of standard tabulations.

4 Quality of registered data is measured in two categories, virtually complete (at least 90 per cent of the events each year are represented) or incomplete (less that 90 per cent representation).

REFERENCES

Arriaga, Eduardo E. 1994a. Population analysis with microcomputer. Volume I: Presentation of technique. Washington, D.C.: United States Bureau of the Census.

Arriaga, Eduardo E. 1994b. Population analyses with microcomputers. Volume II: Software and documentation. Washington, D.C.: United States Bureau of the Census.

Booth, Heather, Maindonald, John and Smith, Len, 2001. **"**Age-time interactions in mortality projection: Applying Lee-Carter to Australia," Working Papers in Demography, No 85. The Australian National University.

Bourgeois-Pichat, Jean. 1978. "Future outlook for mortality decline in the world," Population Bulletin of the United Nations, 12-41.

Coale, Ansley J., Demeny, Paul ; Vaughn, Barbara, 1983. Regional model life tables and stable population, New York: Academic Press.

Coale, Ansley J. and Kisker, Ellen E. 1990. "Defects in data on old-age mortality in the United States: New procedures for calculating schedules and life tables at the higher ages," Asian and Pacific Population Forum, 4,: 1-31.

Coale, Ansley J. 1996. "Age-patterns and time sequence of mortality in national populations with the highest expectation of life at birth," Population and Development Review, 22, 1996, 127-135.

Coale, Ansley J. and Guo, Guang, 1989. "Revised regional model life tables at very low levels of mortality," Population Index, 55: 613-643.

Carter, Lawrence R. and Lee, Ronald D. 1992. "Modeling and forecasting US sex differentials in mortality," International Journal of Forecasting, 8:393-411.

Condran, Gretchen, Himes, Christine L. and Preston, Samuel H. 1991. "Old age mortality patterns in low-mortality countries: An evaluation of population and death data at advanced ages, 1950 to present," Population Bulletin of the United Nations, 23-60.

Duchene, Josianne and Wunsch, Guillaume, 1988a. "From the demographers cauldron: Single decrement life tables and the span of life," GENUS, XLIV:1-17.

Duchene, Josianne; Wunsch, Guillaume, 1988b. Population aging and the limits to human life, Louvain-la-Neuve: Departement de Demographie, University Catholique de Louvain.

Fries, James F. "Aging, natural death, and the compression of mortality,1980. " The New England Journal of Medicine, 303:130-135.

Gavrilov, L. A.; Gavrilova, N. S. 1991. The biology of life span: A quantitative approach, Chur: Harwood Academic Publisher.

Heligman, L. and Pollard, John H. 1980. "The age-pattern of mortality," Journal of the Institute of Actuaries, 107:49-75.

Himes, Christine L., Preston, Samuel H. and Condran, Gretchen A. 1994. "A relational model of mortality at older ages in low mortality countries," Population Studies, 48:269-291.

Horiuchi, Shiro, 1991. "Assessing the effects of mortality reduction on population ageing," Population Bulletin of the United Nations, 38-51.

Horiuchi, Shiro "Postmenopausal acceleration of age-related mortality increase, 1997. " Journal of Gerontology: Biological Sciences, 52A:B78-B92.

Horiuchi, Shiro and Wilmoth, John R. 1997. "Age-patterns of the life table aging rate and major causes of death in Japan, 1951-1990," Journal of Gerontology: Biological Sciences, 52A:B67-B77.

Kannisto, Väinö, Lauritsen, Jens, Thatcher, A. Roger and Vaupel, James W. 1994. "Reductions in mortality at advanced ages: several decades of evidence from 27 countries," Population and Development Review, 20: 793-810.

Lee, Ronald D. and Carter, Lawrence R. 1992. "Modeling and forecasting U.S. mortality," Journal of the American Statistical Association, 87:659-671.

Lee, Ronald D. and Rofman, Rafael 1994. "Modeling and projecting mortality in Chile [Modelacion y proyeccion de la mortalidad en Chile]," Notas de Poblacion, 22:183-213.

Manton, Kenneth G, 1992. "Mortality and life expectancy changes among the oldest-old," in R. Suzman, D. Willis and K.G. Manton, eds., The Oldest-old, New York: Oxford University Press, 157-182.

Manton, Kenneth G., Stallard, Eric and Tolley, H. D. 1991. "Limits to human life expectancy: Evidence, Prospects and implications," Population and Development Review, 17:603-637.

Olshansky, Jay S., Carnes, Bruce A., Grahn, Douglas, 1998. "Confronting the boundaries of human longevity," American Scientist, 86:52-61.

Suzman, Richard M., Willis, David P.; Manton, Kenneth G. 1992. The oldest-old, New York: Oxford University Press.

United Nations. 1997. Projecting old-age mortality and its consequences. Report on the Working Group, 3-5 December 1996, New York: United Nations.

United Nations. 2000. World Population Prospects: The 1998 Revision: Volume III: Analytical Report, New York.

United Nations. 2001a. World Population Prospects: The 2000 Revision: Volume I: Comprehensive Tables, New York.

United Nations. 2001b. World Population Prospects: The 2000 Revision: Volume II: The Sex and Age Distribution of the World Population, New York.

United Nation. 1982. Model life tables for developing countries, New York.

Vaupel, James W.; Lundstrom, Hans, 1994. "The future of mortality at older ages in developed countries," in W. Lutz, ed., "The future population of the world. What can we assume today?" London, England: Earthscan Publications, 295-315.

Wilmoth J. R. 1993. "Mortality projections among the aged in Japan". In Health and Mortality among Elderly Populations: Determinants and Implications, Sendai City, Japan, June 21 to 25, 1993.

Wilmoth J. R. 1994. "Are mortality rates falling at extreme high ages? An investigation based on a model proposed by Cole and Kisker". Population Studies, 94:281-295.

Annex: Tables

Table 1. Smoothed and extended Himes-Preston-Condran mortality standard for older ages

Age	Logit (m_x)		m_x	
	Female	Male	Female	Male
45	-5.945580	-5.429400	0.00261055	0.00436658
46	-5.857527	-5.331900	0.00285016	0.00481161
47	-5.763043	-5.231552	0.00313170	0.00531680
48	-5.670024	-5.131108	0.00343593	0.00587529
49	-5.581900	-5.030498	0.00375128	0.00649312
50	-5.496322	-4.931224	0.00408507	0.00716594
51	-5.413219	-4.830740	0.00443749	0.00791743
52	-5.326582	-4.728463	0.00483714	0.00876258
53	-5.243806	-4.627376	0.00525239	0.00968566
54	-5.159373	-4.527179	0.00571248	0.01069550
55	-5.077452	-4.429220	0.00619713	0.01178329
56	-4.988427	-4.329780	0.00677023	0.01299924
57	-4.897846	-4.230487	0.00740737	0.01433678
58	-4.802196	-4.131314	0.00814482	0.01580785
59	-4.709610	-4.035228	0.00892787	0.01737444
60	-4.614074	-3.940151	0.00981408	0.01907437
61	-4.517492	-3.844479	0.01079848	0.02094929
62	-4.413752	-3.745297	0.01196477	0.02308319
63	-4.308781	-3.645761	0.01327143	0.02543758
64	-4.203867	-3.549564	0.01471785	0.02793440
65	-4.100339	-3.457029	0.01629707	0.03055993
66	-3.995889	-3.367137	0.01805897	0.03333846
67	-3.886589	-3.274687	0.02010279	0.03644987
68	-3.773873	-3.181136	0.02244749	0.03988183
69	-3.659886	-3.087139	0.02508976	0.04364089
70	-3.544304	-2.993253	0.02807758	0.04773160
71	-3.427037	-2.898531	0.03146110	0.05222622
72	-3.304468	-2.799941	0.03541824	0.05732736
73	-3.181927	-2.701239	0.03985155	0.06290029
74	-3.059083	-2.601832	0.04482694	0.06902059
75	-2.939676	-2.504512	0.05022675	0.07554246
76	-2.819954	-2.405958	0.05625535	0.08271951
77	-2.700589	-2.306993	0.06293862	0.09054543
78	-2.578348	-2.205550	0.07054499	0.09925320
79	-2.457149	-2.105523	0.07891733	0.10856114
80	-2.333558	-2.003857	0.08838159	0.11879859
81	-2.209010	-1.899341	0.09894430	0.13018307
82	-2.079846	-1.786644	0.11107121	0.14348462
83	-1.953067	-1.671617	0.12421935	0.15820875
84	-1.829471	-1.558163	0.13830129	0.17391035
85	-1.710777	-1.450972	0.15306301	0.18985199
86	-1.593031	-1.345761	0.16895787	0.20656424
87	-1.474910	-1.240494	0.18619747	0.22434993
88	-1.356319	-1.130236	0.20483923	0.24411763
89	-1.235362	-1.013617	0.22524429	0.26627266
90	-1.111783	-0.888717	0.24753857	0.29137473
91	-0.980186	-0.756307	0.27285497	0.31944867
92	-0.846790	-0.627570	0.30010666	0.34806174
93	-0.716903	-0.506954	0.32807525	0.37590775
94	-0.598880	-0.400472	0.35459997	0.40119889
95	-0.485864	-0.294863	0.38086828	0.42681366
96	-0.371227	-0.187069	0.40824465	0.45336869
97	-0.251530	-0.073442	0.43744695	0.48164769
98	-0.129453	0.041082	0.46768179	0.51026911
99	-0.007377	0.155608	0.49815584	0.53882364

Table 1. **Continued**

Age	Logit (m_x)		m_x	
	Female	Male	Female	Male
100	0.114701	0.270132	0.52864388	0.56712537
101	0.236779	0.384657	0.55891971	0.59499574
102	0.358857	0.499180	0.58876364	0.62226661
103	0.480933	0.613703	0.61796824	0.64878512
104	0.603010	0.728228	0.64634464	0.67441625
105	0.725087	0.842752	0.67372615	0.69904455
106	0.847163	0.957277	0.69997175	0.72257622
107	0.969241	1.071800	0.72496821	0.74493908
108	1.091319	1.186323	0.74863000	0.76608285
109	1.213397	1.300848	0.77089940	0.78597763
110	1.335473	1.415372	0.79174455	0.80461190
111	1.457551	1.529897	0.81115784	0.82199119
112	1.579629	1.644420	0.82915195	0.83813547
113	1.701707	1.758943	0.84575750	0.85307727
114	1.823783	1.873467	0.86101948	0.86685889
115	1.945860	1.987990	0.87499451	0.87953033

Table 2 **UN ultimate life table, males**

Age	$_nm_x$	$_nq_x$	l_x	$_nd_x$	$_nL_x$	T_x	e_x	$_na_x$
0	0.005021	0.004997	100000	500	99529	8207454	82.075	0.057
1	0.000147	0.000588	99500	59	397859	8107925	81.486	1.577
5	0.000065	0.000325	99442	32	497123	7710066	77.533	2.353
10	0.000059	0.000296	99409	29	496976	7212943	72.558	2.583
15	0.000104	0.000518	99380	51	496787	6715967	67.579	2.804
20	0.000194	0.000972	99329	97	496419	6219180	62.612	2.683
25	0.000265	0.001322	99232	131	495843	5722761	57.671	2.582
30	0.000328	0.001641	99101	163	495115	5226918	52.743	2.603
35	0.000463	0.002314	98938	229	494157	4731803	47.826	2.667
40	0.000747	0.003728	98709	368	492702	4237646	42.931	2.704
45	0.001278	0.006371	98341	627	490276	3744944	38.081	2.717
50	0.002228	0.011086	97715	1083	486102	3254668	33.308	2.718
55	0.003904	0.019348	96632	1870	478887	2768566	28.651	2.716
60	0.006842	0.033682	94762	3192	466499	2289679	24.162	2.710
65	0.011966	0.058226	91570	5332	445580	1823179	19.910	2.699
70	0.020833	0.099363	86238	8569	411303	1377599	15.974	2.679
75	0.035979	0.165845	77669	12881	358014	966296	12.441	2.645
80	0.061284	0.266961	64788	17296	282225	608282	9.389	2.588
85	0.102341	0.407386	47492	19348	189051	326056	6.865	2.498
90	0.167970	0.581670	28145	16371	97463	137005	4.868	2.358
95	0.270484	0.762454	11774	8977	33188	39542	3.358	2.139
100	0.440203		2797	2797	6353	6353	2.272	2.272

Table 3 **UN ultimate life table, females**

Age	$_nm_x$	$_nq_x$	l_x	$_nd_x$	$_nL_x$	T_x	e_x	$_na_x$
0	0.003956	0.003942	100000	394	99630	8750205	87.502	0.062
1	0.000083	0.000331	99606	33	398344	8650575	86.848	1.590
5	0.000038	0.000190	99573	19	497815	8252231	82.876	2.363
10	0.000036	0.000178	99554	18	497728	7754416	77.892	2.595
15	0.000060	0.000299	99536	30	497615	7256688	72.905	2.768
20	0.000105	0.000527	99507	52	497411	6759073	67.926	2.675
25	0.000146	0.000729	99454	72	497097	6261662	62.960	2.598
30	0.000187	0.000933	99382	93	496687	5764565	58.004	2.609
35	0.000262	0.001310	99289	130	496140	5267879	53.056	2.660
40	0.000414	0.002068	99159	205	495322	4771738	48.122	2.698
45	0.000699	0.003489	98954	345	493980	4276416	43.216	2.714
50	0.001212	0.006041	98609	596	491684	3782436	38.358	2.719
55	0.002120	0.010547	98013	1034	487706	3290752	33.575	2.719
60	0.003717	0.018430	96979	1787	480814	2803046	28.904	2.716
65	0.006518	0.032109	95192	3057	468961	2322232	24.395	2.711
70	0.011404	0.055563	92135	5119	448901	1853271	20.115	2.700
75	0.019867	0.094960	87016	8263	415919	1404369	16.139	2.681
80	0.034342	0.158883	78753	12512	364346	988450	12.551	2.649
85	0.058833	0.257754	66240	17074	290207	624104	9.422	2.599
90	0.100966	0.403611	49167	19844	196543	333898	6.791	2.516
95	0.173428	0.595387	29322	17458	100665	137354	4.684	2.368
100	0.323372		11864	11864	36689	36689	3.092	3.092

Table 4 **UN model life table for life expectancy at 92.5 years, General Pattern, males**

Age	$_nm_x$	$_nq_x$	l_x	$_nd_x$	$_nL_x$	T_x	e_x	$_na_x$
0	0.000362	0.000362	100000	36	99965	9249994	92.500	0.044
1	0.000021	0.000084	99964	8	399836	9150028	91.533	1.652
5	0.000021	0.000103	99955	10	499751	8750193	87.541	2.500
10	0.000021	0.000104	99945	10	499700	8250441	82.550	2.519
15	0.000023	0.000113	99935	11	499647	7750741	77.558	2.597
20	0.000033	0.000166	99923	17	499579	7251094	72.567	2.652
25	0.000047	0.000234	99907	23	499479	6751516	67.578	2.620
30	0.000059	0.000294	99884	29	499347	6252037	62.593	2.589
35	0.000072	0.000359	99854	36	499186	5752690	57.611	2.632
40	0.000111	0.000555	99818	55	498964	5253504	52.631	2.699
45	0.000187	0.000934	99763	93	498601	4754541	47.658	2.713
50	0.000310	0.001547	99670	154	497997	4255940	42.700	2.723
55	0.000547	0.002733	99515	272	496965	3757942	37.762	2.747
60	0.001018	0.005077	99244	504	495100	3260978	32.858	2.782
65	0.002141	0.010655	98740	1052	491399	2765878	28.012	2.814
70	0.004704	0.023283	97688	2274	483476	2274479	23.283	2.818
75	0.010344	0.050564	95413	4824	466398	1791003	18.771	2.789
80	0.020880	0.099685	90589	9030	432492	1324605	14.622	2.735
85	0.039449	0.180762	81558	14743	373714	892113	10.938	2.689
90	0.076568	0.323716	66816	21629	282484	518399	7.759	2.615
95	0.147071	0.535808	45186	24211	164623	235915	5.221	2.468
100	0.294213	1	20975	20975	71292	71292	3.399	3.399

Table 5 **UN model life table for life expectancy at 92.5 years, general pattern, females**

Age	$_nm_x$	$_nq_x$	l_x	$_nd_x$	$_nL_x$	T_x	e_x	$_na_x$
0	0.001416	0.001414	100000	141	99866	9249982	92.500	0.054
1	0.000028	0.000113	99859	11	399406	9150115	91.631	1.522
5	0.000023	0.000114	99847	11	499208	8750709	87.641	2.500
10	0.000023	0.000115	99836	11	499151	8251501	82.651	2.564
15	0.000031	0.000155	99824	15	499086	7752350	77.660	2.666
20	0.000051	0.000255	99809	25	498985	7253264	72.672	2.665
25	0.000068	0.000342	99783	34	498835	6754279	67.689	2.603
30	0.000084	0.000418	99749	42	498647	6255443	62.712	2.604
35	0.000112	0.000562	99708	56	498407	5756796	57.737	2.655
40	0.000176	0.000881	99652	88	498057	5258390	52.768	2.708
45	0.000306	0.001531	99564	152	497474	4760333	47.812	2.739
50	0.000556	0.002776	99411	276	496436	4262858	42.881	2.749
55	0.001020	0.005087	99135	504	494542	3766422	37.993	2.749
60	0.001859	0.009255	98631	913	491095	3271880	33.173	2.742
65	0.003323	0.016493	97718	1612	484945	2780786	28.457	2.738
70	0.006013	0.029660	96107	2851	474086	2295840	23.889	2.738
75	0.011082	0.054045	93256	5040	454792	1821754	19.535	2.721
80	0.019363	0.092685	88216	8176	422266	1366962	15.496	2.699
85	0.034943	0.161603	80040	12935	370164	944696	11.803	2.678
90	0.064535	0.279800	67105	18776	290942	574532	8.562	2.626
95	0.121696	0.466819	48329	22561	185388	283590	5.868	2.506
100	0.262400	1.000000	25768	25768	98202	98202	3.811	3.811

Table 6 **Coale-Demeny model life table for life expectancy at 92.5 years, North Model, males**

Age	$_nm_x$	$_nq_x$	l_x	$_nd_x$	$_nL_x$	T_x	e_x	$_na_x$
0	0.000527	0.000527	100000	53	99950	9249975	92.500	0.044
1	0.000023	0.000091	99947	9	399770	9150026	91.549	1.857
5	0.000020	0.000102	99938	10	499666	8750256	87.557	2.500
10	0.000020	0.000101	99928	10	499615	8250590	82.565	2.501
15	0.000020	0.000102	99918	10	499564	7750975	77.573	2.515
20	0.000022	0.000109	99908	11	499512	7251411	72.581	2.548
25	0.000026	0.000128	99897	13	499453	6751899	67.589	2.561
30	0.000029	0.000146	99884	15	499385	6252446	62.597	2.606
35	0.000043	0.000213	99869	21	499299	5753061	57.606	2.718
40	0.000083	0.000417	99848	42	499150	5253762	52.618	2.815
45	0.000194	0.000967	99807	97	498819	4754612	47.638	2.784
50	0.000326	0.001631	99710	163	498197	4255794	42.682	2.833
55	0.000959	0.004786	99547	476	496715	3757596	37.747	2.854
60	0.001806	0.008996	99071	891	493365	3260882	32.915	2.768
65	0.003532	0.017521	98180	1720	487078	2767516	28.188	2.779
70	0.007139	0.035128	96460	3388	474666	2280439	23.641	2.748
75	0.012465	0.060591	93071	5639	452409	1805772	19.402	2.704
80	0.021559	0.102645	87432	8974	416271	1353363	15.479	2.673
85	0.035404	0.163424	78457	12822	362153	937092	11.944	2.650
90	0.063061	0.274147	65635	17994	285340	574939	8.760	2.619
95	0.117947	0.455648	47642	21708	184047	289598	6.079	2.505
100	0.245699	1	25934	25934	105551	105551	4.070	4.070

Table 7 **Coale-Demeny model life table for life expectancy at 92.5 years, North Model, females**

Age	$_nm_x$	$_nq_x$	l_x	$_nd_x$	$_nL_x$	T_x	e_x	$_na_x$
0	0.001868	0.001865	100000	186	99824	9250012	92.500	0.056
1	0.000034	0.000134	99814	13	399224	9150188	91.673	1.730
5	0.000023	0.000117	99800	12	498971	8750964	87.685	2.500
10	0.000023	0.000114	99788	11	498914	8251993	82.695	2.546
15	0.000029	0.000146	99777	15	498851	7753078	77.704	2.638
20	0.000044	0.000221	99762	22	498760	7254228	72.715	2.649
25	0.000060	0.000299	99740	30	498631	6755467	67.731	2.618
30	0.000078	0.000390	99711	39	498461	6256836	62.750	2.632
35	0.000112	0.000562	99672	56	498228	5758375	57.773	2.669
40	0.000176	0.000878	99616	87	497879	5260148	52.804	2.720
45	0.000324	0.001620	99528	161	497278	4762269	47.849	2.749
50	0.000583	0.002911	99367	289	496187	4264991	42.922	2.763
55	0.001151	0.005741	99078	569	494116	3768804	38.039	2.763
60	0.002081	0.010357	98509	1020	490236	3274688	33.243	2.738
65	0.003680	0.018250	97489	1779	483400	2784452	28.562	2.728
70	0.006452	0.031791	95709	3043	471607	2301052	24.042	2.719
75	0.011244	0.054807	92667	5079	451680	1829445	19.742	2.706
80	0.019371	0.092706	87588	8120	419175	1377764	15.730	2.689
85	0.033838	0.156825	79468	12463	368304	958589	12.063	2.670
90	0.061509	0.268381	67005	17983	292365	590285	8.810	2.628
95	0.115524	0.448789	49022	22001	190443	297919	6.077	2.515
100	0.251421	1.000000	27022	27022	107476	107476	3.977	3.977