MORTALITY AT ADVANCED AGES IN THE UNITED KINGDOM

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ABSTRACT

As in other developed countries, mortality rates at advanced ages have fallen quite dramatically over the last century in the United Kingdom. However, data have not been readily available for the countries of the United Kingdom (England, Scotland, Wales and Northern Ireland) to calculate mortality rates at individual ages 85 and over. The paper gives an overview of the data that are available and discusses the problems encountered in estimating mortality rates at old ages in the UK. It describes some of the methodologies used to construct mortality rates at advanced ages for official life tables and recent work undertaken by the UK Government Actuary's Department to construct a database of historical mortality rates for the United Kingdom going back to 1961. Possible methods for projecting mortality rates at advanced ages are also discussed.

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1 INTRODUCTION

Although data on numbers of deaths by sex and age at death are available for the United Kingdom, data on the population numbers by year of age for ages 90 and over from which mortality rates at those ages can be calculated are not published (other than for censuses, and even here there are issues of data quality[1]).

Estimates of mortality rates at these old ages are required for a variety of purposes, including the compilation of population life tables and for analysing past trends in mortality to inform the assumptions for projecting mortality at these ages for the UK national population projections. These projections are prepared by the Government Actuary's Department (GAD) at the request of the Registrars General of England & Wales, Scotland and Northern Ireland. GAD also produce official Life Tables for England and Wales (English Life Tables) and for Scotland (Scottish Life Tables) based on population and deaths data for a three-year period around each Census date. Life tables known as Interim Life Tables are also produced annually for the UK and each constituent country; these are calculated using data for consecutive three-year periods.

Until relatively recently, the derivation and projection of mortality rates for the very old were not analysed in great detail because the numbers involved were very small. However, these age groups are now growing and there is substantial interest within government and elsewhere in their projected numbers – particularly with regard to the impact on pensions and the provision of long-term care.

One complexity when considering data at the UK level is that responsibility for producing demographic statistics such as the population estimates and numbers of deaths for each country of the United Kingdom falls to the different Registrars General of England & Wales, Scotland and Northern Ireland. Statistics relating to the United Kingdom as a whole are then obtained by aggregation. This can lead to some difficulties where the individual countries collect or publish data in different ways or where past data are available for differing periods within each country.

Section 2 of the paper gives an overview of the data that are available and discusses some of the problems encountered in estimating mortality rates at old ages in the UK. Section 3 describes some of the methodologies used to construct mortality rates at advanced ages for official Life Tables. Section 4 discusses some of the methodologies proposed for estimating mortality rates at ages 85 and over. Section 5 discusses the results of an investigation into suitable methods for estimating mortality rates at old ages in the United Kingdom, carried out as part of a recent review of the methodology for projecting mortality rates in the UK national population projections. Section 6 and 7 describe recent work undertaken by the UK Government Actuary's Department to construct a database of historical mortality rates for the United Kingdom and constituent countries going back to 1961 and the mortality rates derived from this database. Possible methods for projecting mortality rates at advanced ages are discussed in Section 8. Section 9 discusses some of the findings of the papers and Section 10 provides a short conclusion.

2 DATA SOURCES

The principal sources of data available to estimate age specific population mortality rates in the United Kingdom and its constituent countries are the mid-year population estimates and the numbers of deaths, subdivided by age and sex, provided by the Registrars General for England & Wales, Scotland and Northern Ireland. Data for the UK are obtained by aggregation.

2.1 Population data

The decennial population censuses provide the base figures from which official national population estimates for each country of the UK are derived. Censuses have been carried out every ten years since 1841, excepting 1941. The population estimates are obtained by rolling forward the estimates by age and sex produced after a census using data on subsequent births, deaths and net migration. These rolled-forward estimates are generally subject to increasing error as they move further away from the last census year and are eventually revised following the next census. It might be expected that the estimates derived for a census year should be the most reliable since it is a legal requirement in the UK to complete and return census forms. However, data from previous censuses have had to be adjusted to allow for undercounts of certain population subgroups. Also, as generally acknowledged, census data for the very old are less reliable because of age misreporting (Humphrey 1970, Thatcher 1992). Errors were found in the data in the 1971 and 1981 Censuses, where verification checks were carried out on a sample of those at old ages. For example, of the 3,727 supposed centenarians in the 1981 Census data, only 1,644 could be successfully traced through the National Health Service Central Register, which allows the date of birth to be checked against previous declarations. There were many cases where the age differed by a very round number such as 10 or 20 years. Other processing errors were also found. As a result, population estimates for the UK and the constituent countries are not published by single year of age and sex for ages over 90 because of their dependence on the census figures at high ages. No checks were carried out on the centenarian ages in the 1991 Census, although the number of centenarians produced in the 1991 Census appeared high compared to other sources and estimates of the total number of centenarians in 1991 (Thatcher 1994, 1999).

As well as misreporting of ages recorded at advanced ages in censuses, misreporting of age at date of death can introduce further errors into the population estimates.

Subject to the above considerations, the quality of the population estimates is thought to be good. Although some administrative data sources (birth registrations, school rolls and pensions data, for example) can be used to check information about various age groups, there are generally no other sources of population estimates for the UK or its constituent countries against which comparisons can be made.

Population estimates are usually published showing numbers as at the mid-point of each calendar year, by sex and age last birthday at that time. The data that are available for each country of the UK are described in Appendix A.

2.2 Deaths data

Numbers of deaths by age and sex up to the oldest age of death on a calendar year basis are available from 1910 onwards for England and Wales combined. For Scotland, deaths are available by single year of age up to 99, with aggregate totals for ages over 100 for the period 1911 to 1973 and up to the oldest age of death from 1974 onwards. For Northern Ireland, deaths to the oldest age are available from 1968. Before that the numbers are available up to age of 99, with aggregate totals for ages 100 and over

Since registration of death before a body may be buried or cremated has been a legal requirement in each country of the UK for many years, registration of deaths is believed to be virtually complete. Registration and certification of deaths usually follows a standard procedure throughout the UK. Except in circumstances that involve referral to a coroner, a doctor must produce a medical certificate. This is taken to the registrar who completes the registration details using information provided by the informant (a person legally allowed to register the death). There are various checks on the entry and validation of the data supplied, although not all the information provided may be internally verifiable other than for certain aspects of its consistency.[2,3]

All deaths registered in England and Wales or in Scotland, whether of residents or non-residents of that country, are included in the data for that country. Deaths of non-residents in Northern Ireland have only been included in the data since 1991. Deaths of people normally resident in the UK which occur and are registered abroad are excluded from the figures.

Because of the legal requirement to register deaths and the various procedures outlined in the previous paragraph, these data are thought to be reliable, even for the very old (Thatcher and others). However, a recent exercise by the Northern Ireland Statistics and Research Agency has suggested that there is some incorrect notification of the date of birth, and hence the age at death, in Northern Ireland, particularly for the very old, with an estimated 5 per cent of death certificates showing age at death in excess of 90 years old being in error by at least two years. There are no other sources of data on deaths for each country as a whole.

2.3 Other sources of data

Although there are no other sources for making population estimates and deaths by age and sex covering each country of the UK, the Department for Work and Pensions (DWP) maintains a 5 per cent sample (based on National Insurance numbers) of pensioner data which is regularly updated, with notified deaths being removed and the relevant new pensioners added.

The DWP are also involved in the identification and verification surrounding the sending of messages of congratulations by the Queen to people reaching their 100th birthday and also to those reaching their 105th and each successive birthday. Data are available on the number of such messages issued each year. In practice, lists of potential recipients are compiled every few weeks prior to the relevant birthdays. Verification checks are carried out and a record is kept of cases verified and whether a message is requested or not. Since messages are not issued to everyone and there may be problems covering those in communal establishments, these data do not provide accurate numbers of the very elderly. However, they can provide a lower bound on numbers at the oldest ages.

There are organisations other than the national statistical offices of the Registrars General that collect mortality data from subgroups or samples of the population. For example, the Continuous Mortality Investigation Bureau set up by the UK actuarial profession collects data on various population subgroups that have insurance contracts including annuities for life and publishes mortality rates derived from these data. Such investigations often apply only to subsections of the population that are not, usually, representative samples of the whole population. Thus the resulting mortality rates by age and sex are not necessarily indicative of those for the whole population.

Other sources that could provide useful data to inform analyses of past and future trends are longitudinal surveys, which take a sample of people and follow progress throughout their lives. Such studies allow for an analysis of mortality that links various characteristics of the sample's members, something that is not possible using death registrations, which contain only a small amount of extra information. However, it is difficult to find the characteristics of a relatively small population, which the very elderly comprise, from such sample surveys. Also, most longitudinal surveys in the UK have not been in progress for very long periods.

Difficulties in analysing mortality rates for the very elderly in the UK can arise since a relatively large proportion of the very elderly is in communal establishments rather than households; this can cause problems for data collection for longitudinal studies and such institutions are outside household surveys.

3 NATIONAL POPULATION LIFE TABLES

A series of Life Tables, based on data for England and Wales combined (but somewhat confusingly termed the English Life Tables[4]), have been produced at fairly regular intervals since 1843. The reports on the Life Tables have traditionally contained a record of mortality rates at each age, calculated as accurately as possible from death registration data and population numbers and a graduated set of those rates. The latter, together with the resulting life tables, have been used in the past as a standard for various purposes such as the assessment of monetary lump sums awarded as damages in court cases involving fatal accidents and personal injuries.

A similar set of tables have been produced for Scotland beginning with tables based on the Census and deaths of 1871. Life Tables have also been produced for Northern Ireland on an irregular basis. Abridged Life Tables for Scotland and for Northern Ireland have also been produced on a regular basis by the respective Registrars General for those countries.

In general, the national life tables are produced by applying a method of graduating derived crude death rates over an age range starting with the young and usually ending in the eighties or nineties. Mortality rates at the very youngest ages are usually compiled directly from the records of births and deaths at these ages. Often, the main graduation method used does not work well at the oldest ages beyond 90 and a separate method is used at these ages.

A brief description of the methodologies used for graduating mortality rates at the oldest ages in the English Life Tables produced during the twentieth century is given in the following section. Further details, together with descriptions of the methodologies used to graduate mortality rates over the younger ages, are included in the appropriate English Life Table publication.

3.1 Methods used in national Life Tables for estimating and graduating mortality rates at old ages over the twentieth century

English Life Tables

A range of methods have been used to graduate mortality rates at the oldest ages in the English Life Tables (ELTs) produced over the twentieth century. Most of these involve some form of extrapolation from the rates graduated over the main body of the tables.

The first English Life Tables produced in the twentieth century, ELT No 7 (1901-10), were based on data for 1901-1910. The main criteria adopted in deciding on a method for graduating the data for ELT7 were that the method should be simple in theory, easy in application, produce curves of smooth graduation and curves which adhere closely to the original data, with the last being the most important desideratum. The report suggests that the previous ELT Nos 1-6 showed mortality rates that were felt to be too low at the oldest ages. The report discusses the existence of exaggeration and mis-reporting of age, both in the censuses and at death. It was noted that if the same misstatements appeared in the same proportions in both the census and in registering deaths, and if on both occasions the same misstatements occurred, the result is to understate the rate of mortality. However, the extent of age misstatements was not known and no correction was attempted.

ELT7 used census data for 1901 and 1911 to derive the exposed-to-risk by age and sex over the period 1901 to 1910. Data from the Censuses were provided in quinqennial age groups up to 99 and a further group of 100 and over. The mean populations were then derived in 5-year age groups up to 100, with a final group of 100 and over. This latter group was then divided into 100-104 and 105 in the same proportions as existed among centenarians enumerated in the 1911 Census. Deaths data for the period was derived by apportioning the deaths in various age groupings according to the distribution of the deaths in the three years 1910-12, to obtains numbers of deaths in the same age groupings as the population figures. Graduated quinquennial pivotal values for the population and the deaths respectively were then derived for each age group 5 to 9 to 100 to 104. Values of the central death rate, m_x, were then obtained by dividing the pivotal value of the number of deaths by the pivotal value of the population for ages 12, 17, to 97. These values were then converted to rates of mortality using the formula $q_x = 2m_x / (2 + m_x)$, where q_x is the probability that someone aged x will die before reaching age x+1.

The intervening values of the rates of mortality for ages 17 to 92 were then obtained by osculatory interpolation between transforms of the quinquennial values of q_x. This method of graduation became known as King's method named after the actuary, George King, who proposed the methodology and who carried out the preparation of the Life Tables. The method was used to prepare several subsequent English Life Tables.

To complete table at the oldest ages, values of log p_x for 89, 90, 91, 92 and 97 were used to obtain values of fourth differences (where $p_x = 1 - q_x$). The life table was then completed from age 93 upwards by summation of these differences.

A similar method was used for producing ELT No 8 (1910-12).

This method of extrapolation at the oldest ages was found to produce decreasing values of q_x after age 100 when used to construct ELT No 9 (1920-22). A 'Gompertz' graduation was used to obtain values of q_{85} upwards. Examination of the data suggested that $\log_{10} p_{89}/\log_{10} p_{84}$ was approximately equal to the value of $\log_{10} p_{94}/\log_{10} p_{89}$. The tenth root of $\log_{10} p_{94}/\log_{10} p_{84}$ was applied to $\log_{10} p_{84}$ to give values for q_{85} upwards. The values obtained by this method were adopted for all ages above 84.

Gompertz extrapolation was again used in ELT No 10 (1930-32) to produce values of q_x from age 87 upwards, based on an examination of the values of $\text{colog } p_{x+5}/\text{colog } p_x$ which gave a good agreement of the actual and expected numbers of deaths. The resulting mortality rates appeared to be heavy for ages 95-99 compared to the actual number of deaths recorded. However, the numbers of deaths recorded at these ages appeared small compared to numbers at ages 90-94, especially for males.

The report on the next English Life Tables (No 11 1950-52) commented that King's method automatically produces, over each 5-year age group, a very close agreement between actual and expected deaths. This is obtained by retaining features which a more powerful method of graduation would obliterate as of no real significance. Also, the method does not graduate crude death rates since ungraduated rates are not calculated. Since population numbers and deaths are graduated separately, the method is also susceptible to features that affect population numbers but not the mortality rates, such as fluctuations in numbers of births. Pivotal values at oldest ages are likely to be unreliable and, in previous ELTs, the graduated values for oldest ages was carried out by ad hoc methods which bore no relation to the main method used for graduating the mortality rates.

As a result, other methods were investigated which were more closely akin to those being used to graduate the mortality experience of assured lives and annuitants. Based on a study of the run of pivotal values of m_x and, in particular, of the ratios m_{x+5}/m_x, it was found that for males from age 21 and for females from age 27 national mortality rates could be represented very closely by a mathematical formula of similar form for each sex. These curves were consisted of a combination of a logistic curve and a normal curve, of the form:

$$m_x = a + b/(1 + e^{-\acute{a}(x-k))}) + c.e^{-\hat{a}(x-n)\text{\^{}}2}$$

The logistic part of the curve contributed by far the greater amount to the values of m_x at the oldest ages.

The graduated mortality rates gave expected deaths for men aged 95 and over which were 10 per cent higher than the actual number. The crude rates at these ages seemed to be low compared to those in the 90-94 age group, a feature which was apparent in the 1930-32 data, and it was felt that this was due primarily to misstatements of age.

ELT No 12 (1960-62) was similarly graduated by fitting a mathematical curve to the ungraduated mortality rates.

The fitting of a mathematical curve to the ungraduated data proved problematical for the preparation of ELT No 13 (1970-72). The method adopted was graduation by cubic splines for ages 2 to 95 for each sex. This involves fitting third order polynomials to sections of the data, the polynomials being chosen so that they and their first two differential coefficients are continuous at the boundaries of each section (known as knots). The graduations were completed by extrapolation, assuming a limiting age of 110, although no details are given in the report of the extrapolation method used.

ELT No 14 (1980-82) were the first English Life Tables to use an exposed to risk calculated from the mid-year population estimates rather than the enumerated census population adjusted by data on registered deaths. Graduation by cubic splines was again adopted. At ages over 95 the underlying data were felt to be suspect and the crude death rates formed an erratic set of values. For males over age 92, the central death rates were extrapolated using a cubic polynomial determined by requiring it to have the same value and first and second derivatives at age 92 as the quadratic defined by the graduated values of m_{90}, m_{91} and m_{92} and a somewhat arbitrary value of m_x of 0.75 at age 105 taken from data collected for an investigation of the mortality of centenarians covering the years 1950 to 1979.[5] For females, the extrapolation was carried out in a similar manner, but over the age range 93 to 95 with a value for m_{105} of 0.65. The value of q_{112} was taken to equal 1 for both men and women.

The exposed to risk for ELT No 15 (1990-92) was determined from the mid-year population estimates for 1990, 1991 and 1992 for ages up to 89. However, these estimates were not provided at individual ages over 90. The age distribution in the 1991 Census for ages over 90 was also felt to be unreliable. A method based on survival rates was used to estimate age distributions for those aged 90 and over for each year 1990, 1991 and 1992. These age distributions were then applied to the official population estimates totals of those aged 90 and over for the relevant year to obtain revised numbers at each age. It was found that the method used gave population estimates at ages just under 90 that were close to the official estimates.

The method of reverse survival rates used involved firstly calculating, for each age x for each calendar year up to and including 1993, the ratio of the numbers of deaths at ages $(x-2)$ to $(x+2)$ in the calendar year to the number of deaths aged $(x-3)$ to $(x+1)$ in the previous year. These ratios were then extrapolated into future years. The estimated numbers of deaths at each age x in the years from 1994 onwards were then obtained by applying the appropriate projected ratio of deaths at age x in the year to the number of deaths at age $(x-1)$ in the preceding calendar year. The population numbers at each age 90 and over in 1990, 1991 and 1992 were then obtained by summing the deaths backwards along a cohort from the future year in which the deaths for the cohort were projected to be negligible.

The resulting crude death rates were graduated using natural cubic splines, with knots at each of the data points. The method could be extended to the highest ages as the values at these ages have little effect on the graduation at younger ages. However, a cut-off point was taken at those ages beyond which the crude death rates ceased an upward progression, otherwise the graduating spline may turn downwards. As a result, the maximum age was chosen to be 102 for males and 104 for females.

The method used in ELT No 14 for extrapolating mortality rates for the oldest was not adopted since it was found that the resulting extrapolated values depended critically on the arbitrarily chosen fixed values and the initial conditions. Experiments using straight line extrapolations of m_x (or implied q_x), and transforms of these rates suggested that the most satisfactory results, judged on the basis of age-to-age progression of the mortality rates and the relationship between the extrapolated male and female rates, were obtained by using a regression line fitted to the values of the function $\ln(q_x/(1-q_x))$ from ages 85 to 103 for males, (104 for females) and then extrapolating beyond. The extrapolated values of $\ln(q_x/(1-q_x))$ were converted back to give values of q_x directly. An arbitrary limiting age of 121 was chosen for both males and females for the resulting Life Tables.

Figures 1 and 2 show the resulting published graduated values of q_x for ages 80 to 104 for males and for ages 80 to 106 for females for a selection of English Life Tables over the twentieth century. As can be seen the shape of the mortality curve varies between the different ELTs. The figures illustrate the wide disparities that arise from the differing methods adopted to graduate mortality rates at the oldest ages in the life tables. Mortality rates at these ages were assumed to increase most rapidly for ages 100 and over in ELT No 8. Recent ELTs show a more gentle increase in mortality at the oldest ages. Different patterns emerge for males and females. For example, whilst mortality rates in the ELTs for 1970-72 and 1990-92 converge for males, they diverge for females. Interestingly, the curves for ELT No 11, which were graduated using an amalgam of a logistic and a normal curve, display mortality rates which increase at a declining rate at the oldest ages for both males nad females. These may be more in line with the latest thinking on the pattern for mortality rates at the oldest ages, which several commentators have suggested can best be modelled by a logistic function (Thatcher 1998).

Similar patterns can also be seen in figures 3 and 4 which show the mortality rates derived from each the most recent ELTs from 1950-2 onwards. Whilst the rates for a given age decrease for successive life tables for ages up to the mid-nineties, crossovers occur at higher ages and the rates of increase in mortality rates with age vary considerably. Because of the different methodologies used to graduate mortality rates at ages 90 and over for each ELT, it is difficult to disentangle the actual underlying changes in mortality at these ages from the effects of the changes in methodology.

3.2 Scottish and Northern Ireland Life Tables

Scottish Life Tables have generally been produced at the same time as English Life Tables and usually adopted the same graduation method as was used for the corresponding ELT except for the 1950-52 tables when King’s method (together with the Gompertz extrapolation for mortality rates at the oldest ages) was used for Scotland rather than fitting a mathematical curve.

Life Tables for Northern Ireland were published after the Census of 1926 – these were based using King’s method but based on using data in 10-year age groups rather than 5-year age groups. A second set of tables were produced covering the period 1950-52. The graduations for these tables were carried out by fitting mathematical curves to the data. For females, a logistic curve was found to suffice; for males, a good fit was found in increasing the resulting rates for women by 10 per cent and adding a second term equivalent to a normal curve.

Figure 1 - Probabilities of dying by single year of age - Males qx
(Source: English Life Tables)

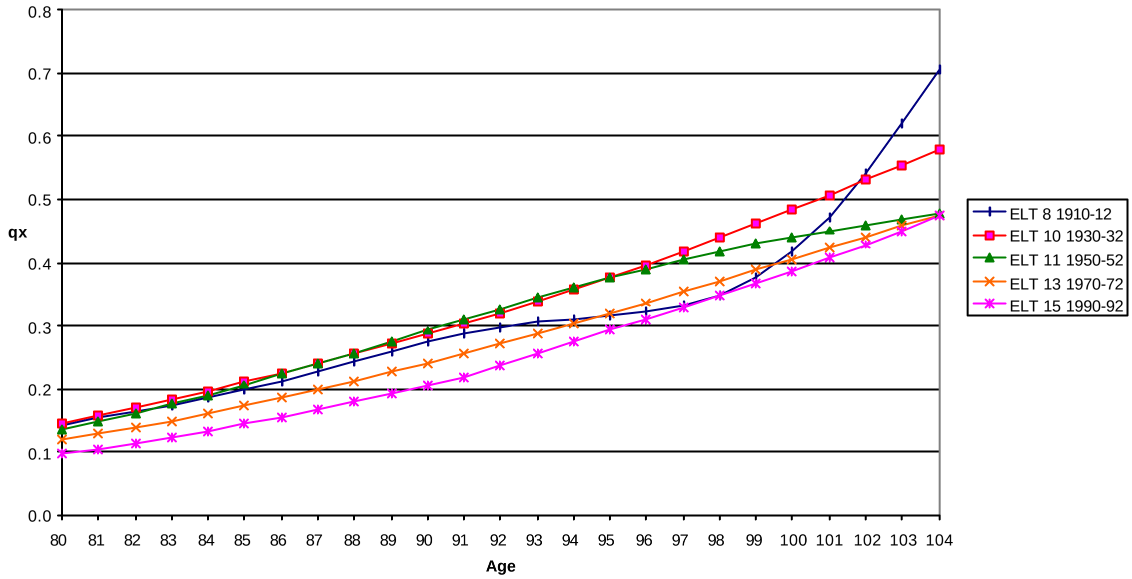


Figure 2 - Probabilities of dying by single year of age - Female qx
(Source: English Life Tables)

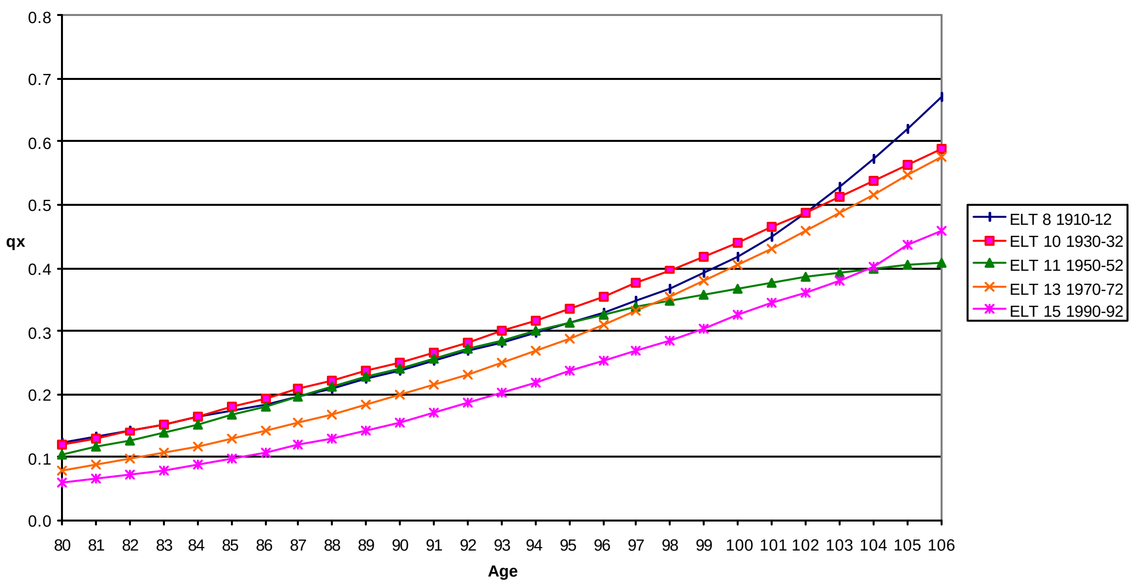


Figure 3 - Probabilities of dying by single year of age - Males qx
(English Life Tables 1951-1991)

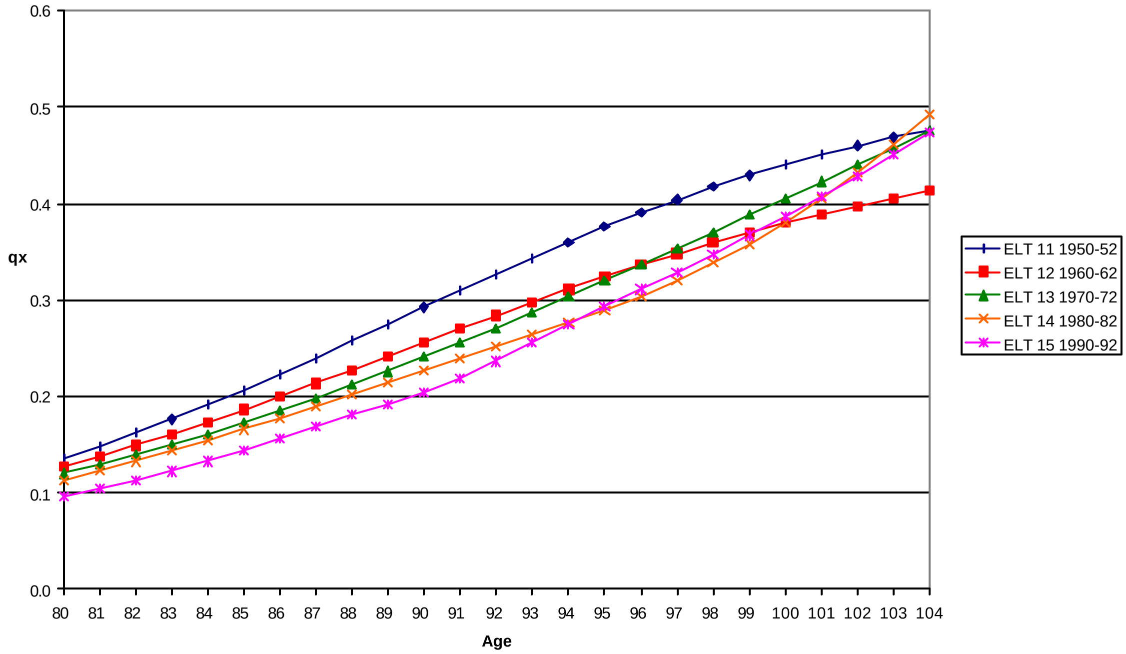
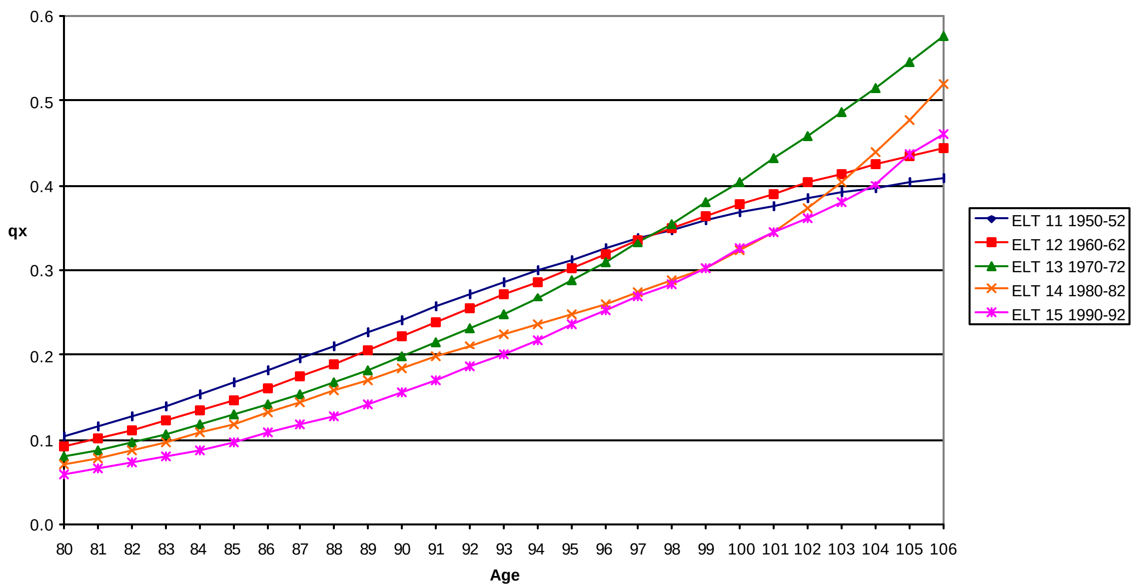


Figure 4 - Probabilities of dying by single year of age - Females qx
(English Life Tables 1951-1991)



3.3 Interim Life Tables

As well as the detailed investigations which take place following a census to prepare the decennial national Life Tables, Interim Life Tables are also produced annually. These are calculated from ungraduated mortality rates derived from data on deaths and population estimates for three consecutive calendar years (for example, 1997 to 1999). These life tables are produced for each country of the UK as well as for Great Britain and the UK as a whole. The derived crude values of m_x are converted to values of q_x using the formula $q_x = 2m_x/(2 + m_x)$. Values of m_x and q_x are calculated up to age 110; however because of the small numbers of deaths involved at these ages and since the resulting crude death rates are not graduated these values are only published up to age 100. Where there are no deaths recorded at a given old age, m_x is assumed to equal 0.5.

For years which are the base year of a set of the national population projections (usually every second calendar year) the population estimates by year of age for those aged 90 and over for 1996 onwards are taken to be those used for the base year. In the past, these have been derived in differing ways, most recently using variants of the extinct generation method described later in section 4 of the paper. In each case the resulting estimates were adjusted to equal the official total estimates for the population aged 90 and over by a simple scaling factor.

Population estimates at these ages in years which are not the base year of a set of projections have been created by ageing on the assumed base year population using deaths figures by age and assuming nil migration. The resulting total estimates for ages 90 and over are then adjusted to equal the official estimate of this total. In all cases, in calculating the death rates, deaths and population estimates for ages 110 and above are amalgamated.

4 METHODS FOR ESTIMATING MORTALITY RATES FOR PEOPLE AGED 85 AND OVER

Various methodologies have been proposed for estimating population numbers and mortality rates at these oldest ages. Most of these generate population numbers from death registrations. For the purposes of estimating the number of very old people, these data are considered to be more reliable than estimates obtained from censuses. These methods include the well-known method of extinct generations (Vincent 1951) and the survivor ratio method.

The method of extinct generations is a way of generating population numbers from death registrations. It is based on the assumption that when all the members of a given cohort (in this case, people born in a given calendar year) have died, the numbers that were alive earlier can be reconstructed if the dates of death of everyone in that cohort are known. This assumes that international migration can be ignored, which will usually be the case if the method is confined to ages that are high enough and if death registration data are accurate. Ideally, the method requires data on deaths by year of birth and age at death.

The survivor ratio method is a modified version of the extinct generations method that does not involve waiting until all the members of a cohort are dead. At old ages only a small proportion of the original members of a cohort will still be alive. It is assumed that the ratio of the number of survivors to the number in the cohort who died over a given period can be estimated from the experience of previous cohorts. This 'survivor ratio' can then be applied to the number of deaths for a cohort over the same number of years to obtain estimates for the number of survivors.

This gives an estimate of the number of survivors in cohorts that are not yet extinct. The population of these cohorts in previous years can then be constructed using the number of deaths in previous years, as in the extinct generations method.

The method requires qualitative judgements on a number of issues: the number of years' deaths to include in the denominator of the survivor ratio; the number of cohorts across which to average survivor ratios; and the nature of this averaging (weighted or unweighted, for example). If mortality rates are falling over the period chosen, a further correction factor could also be introduced. If reliable estimates for the total population are available, say, for the over-90s, but these estimates aren't reliable for individual ages, then a correction factor can be applied so that the estimates agree with this total.

Another data-driven method that might be used for ascertaining death rates at older ages would be to extrapolate from the rates for ages up to 85, the highest age for which rates can be determined from data available. This approach is discussed by Boleslawski and Tabeau (2001), who consider the performance of 14 different models for extrapolating the age pattern of mortality among the over-85s, using data for individual years of age for France, the Netherlands and Norway. Their findings are that a polynomial of degree five or six, fitted using the weighted least squares method, provided the best extrapolation for cases where mortality data for the over-85s are not reliable and satisfactory data exist for ages between 60 and 84.

There have been several investigations of various models proposed for mortality at old ages. A database containing the available official statistics on deaths at ages 80 and over in 30 countries since 1960 (and earlier, in many cases) is held at the Max Planck Institute for Demographic Research in Rostock, Germany and has been analysed extensively. Thatcher *et al* (1998) have tested six possible models for mortality above ages 80 fitted to data sets comprising 13 industrialised countries from the database for overlapping periods 1960-70, 1970-80, 1980-90 and for the cohorts born in 1871-80, for males and females separately. This research suggested that the data were closer to the logistic model than to the Gompertz, Weibull and Heligman and Pollard models.

Thatcher (1999) has fitted logistic functions of the form $ì_x$ = êz/(1+z) + ã to data from the English Life Tables and other historic Life Tables from the mediaeval period onward, where

$ì_x$ is the force of mortality,
ê was taken to equal 1,
z = á exp(âx) = exp[â(x-ö)], with ö= - ln(á)/ â.

The results show that over the period 1841 to 1981, á has decreased quite dramatically, â has risen very slowly from around 0.10 to 0.11, and thus ö has increased, whilst ã had become negligible. In terms of interpretation the force of mortality is dominated by ã at ages in the thirties and by ö at the oldest ages (90 and over). á is the dominant parameter in the middle range of ages and â is a measure of the relative rate at which the force of mortality increases with age.

5 ESTIMATES OF MORTALITY RATES FOR THOSE AGED 85 AND OVER IN THE UNITED KINGDOM

As discussed earlier, mortality rates by single year of age for the over-90s cannot be calculated directly by dividing numbers of deaths at a given age by the mid-year population at that age, because the annual population estimates are not available by single year of age for these ages. For the decennial life tables, these rates have usually been estimated by extrapolation from graduated rates for younger ages.

The growth in numbers at these oldest ages is giving rise to substantial interest in their projected numbers – for example, with regard to the impact on pensions and the provision of long-term care. As a result, greater attempts have been made from the early 1990s to allow for more detailed analysis of the actual past mortality trends at those ages when setting assumptions for use in the UK national population projections.

Various methodologies proposed for estimating and projecting mortality rates at ages over 85 were examined as part of a recent review of the methodology for projecting mortality rates in the UK national projections.[6] These included deriving estimates using extinct generations and survival ratio methods, fitting curves to mortality rates over the entire age range and methods involving extrapolation of past trends such as the Lee-Carter methodology (Lee 2000). Alternative sources of data were also investigated.

Kannisto and Thatcher have constructed a database, covering the years 1911 to 1998, that gives population estimates for England & Wales by sex for each individual age from age 80 to the highest attained age. This is based on the methods of extinct generations and survivor ratios described earlier (labelled the KT method for ease of reference in this paper). These results agree with work done by GAD, apart from minor differences due to rounding.

The Kannisto-Thatcher method produces population estimates as at 1 January and, to do so, requires only the numbers of deaths by age as at that date. As deaths data for UK countries are only published as 'age at death', each figure for calendar year deaths is split between the two cohorts affected, with half allocated to each cohort. Kannisto (1988) has suggested that at ages over 100 the split is nearer to 55:45 than 50:50, but that below age 100 the split is nearer 50:50. Thatcher (1992) has carried out calculations using both assumptions which suggest that assuming a 50:50 split has little effect on the values of q_x compared to those derived assuming a 55:45 split.

Andreev (1999) has analysed the existence of age-heaping (the tendency to record ages ending in certain digits) in death registrations in the Kannisto-Thatcher database. For England and Wales there was some evidence of age-heaping in the years 1911 to 1980 at ages 81 and 91 for males and females and also age 84 for females, with age-heaping being more evident for females than males. No evidence was found in the database for Scotland. There was no evidence of age exaggeration for the data for England and Wales or for Scotland.

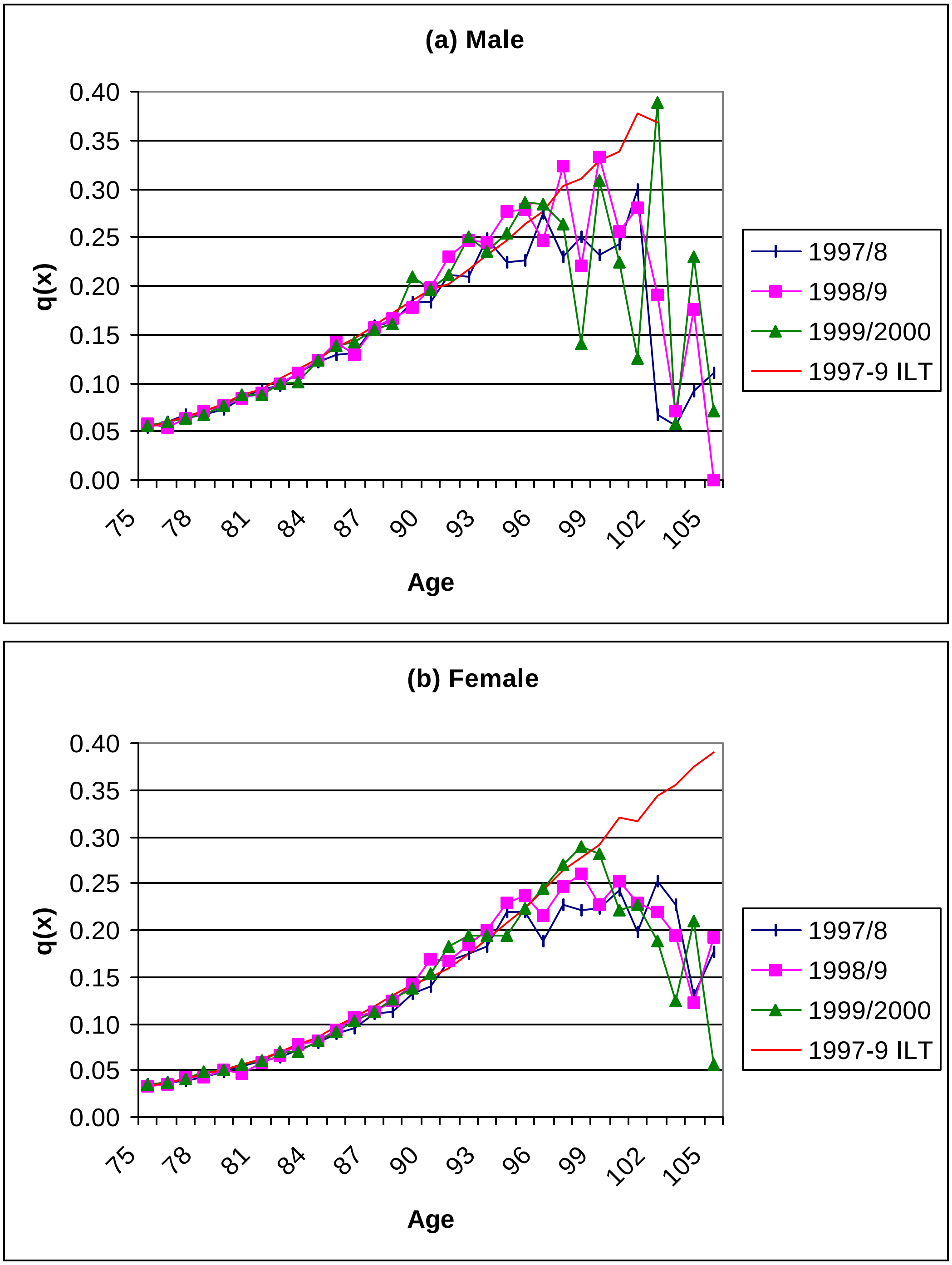
The Max Planck Institute for Demographic Research has tested the survivor ratio method against the method of Das Gupta (Das Gupta 1990) and a new method called the decline of mortality method, proposed by Andreev as part of a wider study of the database (Andreev 1999). These methods were tested on data for 13 countries and the result suggested that the survivor ratio method, linked to the official population estimates for the total at ages 90 and over performed better than the other methods. The survivor ratio method has been chosen to be applied to countries which do not have reliable population registers when updating the database. Full details of the tests and criteria are available from the Max Planck Institute.

The 5 per cent sample (based on the National Insurance numbers of people covered by the UK social security system) of the database of those in receipt of state pensions held by the Department for Work and Pensions was investigated as an alternative source of data on mortality rates at old ages. This database, which should contain everyone in the population in receipt of state pension, is regularly updated, with notified deaths being removed and the relevant new pensioners added. Mortality rates can be determined by a comparison of the numbers aged x in one year and $x+1$ in the next year. The latest figures, however, suggest that there is a discrepancy between the DWP pensioner data and numbers at old ages derived from the Kannisto-Thatcher method. Figure 5 compares the probability of someone aged x dying before reaching age $x+1$ (q_x) derived from DWP data covering 1997 to 1999 (inclusive) with those from GAD's interim life tables (ILTS) which were produced using population data for the same period. For ages above 90 the age distribution of the population used in the ILT have been broadly derived from the Kannisto-Thatcher age distributions. Up to about age 97, the shape of the rates derived from the DWP data matches the ILT curve. Beyond this point the rates diverge.

There are reasons why the figures rated up from the DWP sample would not necessarily equal the official population estimates, related to factors such as foreign residents in the UK not entitled to receive state benefits, former residents living overseas who have their state pensions paid through UK bank accounts, late deletion of deaths. However, the DWP data imply that in Great Britain the number of centenarians is around 240 per cent greater in 1999 than in 1991. The number of deaths of centenarians over the period has only risen by around 50 per cent. If both these were true, they would imply implausibly high reductions in mortality rates for ages over 100.

Data on the number of messages sent by the Queen to people aged 100 and 105 and over also suggests there has been a much smaller increase in this population group over the period 1991 to 1996 than the number of pensioners recorded in the DWP sample. Given these various concerns, the use of this database as an alternative source of data for deriving mortality rates for the very old has been discounted at present.

Figure 5 Comparison of 1997 to 1999 Interim Life Table mortality rates with rates calculated from financial year DWP pensioner data



The fitting of mathematical curves to mortality rates derived for all ages was also investigated as part of the review. Practical difficulties were found in attempting to fit one curve to the entire age range of UK data and it was felt that, even where a curve could be fitted, the projection of the parameters of the curves could well be problematic and this option was not pursued further. However, fitting of curves to the oldest ages only may be a useful way of graduating the crude mortality rates at these ages calculated using deaths data and population estimates derived from a survivor ratio method.

The other sources of UK data on numbers of very old people discussed in this section appeared to be less reliable or credible in terms of the shape of the mortality rates produced as compared with those given by the Kannisto-Thatcher method. The review concluded that the Kannisto-Thatcher survivor ratio method appeared to give reliable population figures that can be used to produce mortality rates at older ages for the UK and its constituent countries.

6 CONSTRUCTION OF A UK DATABASE OF HISTORIC MORTALITY RATES FOR THOSE AGED 85 AND OVER

Methodology and calculation

This section discusses the work currently being carried out within GAD to construct a database of historical population estimates, and hence mortality rates, for the UK and its constituent countries using the Kannisto-Thatcher survivor ratio method. A detailed description of the method is available in an unpublished paper.[7] The estimates produced for the final year of the database are controlled so that the totals of the estimates for those aged 90 and over by sex are equal to the official estimates of the population aged 90 and over by sex for that year. A choice has to be made as to the numbers of cohorts and previous years to be used for calculating the survivorship ratios. The survival of the five preceding cohorts over a five-year period has been used, in line with the parameters used in the database kept by the Max Planck Institute for Demographic Research. Work on checking the database constructed is still ongoing and hence the results given in this paper are provisional only.

There are some problems with using such a model for UK purposes. Firstly, the assumed split of deaths in a calendar year between cohorts is somewhat arbitrary. Second, the method produces population estimates as at 1 January rather than the mid-year estimates required. The latter are obtained by interpolation. Consideration is being given as to whether the method can be adapted to provide mid-year population estimates directly. This would require deaths figures on the basis of mid-year to mid-year numbers by age defined at either the beginning or the end of the period. However, it may be that the errors involved are relatively small, at least for the purposes of making projections.

The method also depends on the data on ages at death being correct. Although the data for the United Kingdom is believed to be good because of the requirement to register deaths, age misreporting may still occur, as suggested by the study carried out in Northern Ireland, mentioned in section 2.

Another problem can occur at the ages where the estimates derived from the KT method are joined to the official estimates. For example, the official estimates may be thought reliable at a given age such as 89, or for the total for ages 90 and over, say. It is desirable that a relatively smooth run into the official ones can be obtained. This can be achieved to some extent by adjusting the correction factor in the method to provide the requisite figures for recent years, although this may not work consistently for estimates for earlier years. An alternative approach where the total for an age group is used as a control is to apply the age distribution produced by the KT method for a particular year to the control total for that age group from the official estimates to obtain estimates for each year of age which total the official estimate.

Whilst the KT method may be used for countries of any population size, problems of consistency may arise where estimates are also required for smaller regions. In the UK, estimates are required for the UK as a whole and for each individual country. This leads to considerations of whether the KT method should be applied to produce United Kingdom estimates from an aggregate of UK deaths, with the results disaggregated in some way to provide estimates for each constituent country or whether it might be applied to each country individually with UK figures obtained by aggregation. Given that the population estimates are provided separately for each country by the relevant national statistical offices and data for the UK is obtained by aggregation, it was decided that databases would be constructed for England and Wales combined, for Scotland and for Northern Ireland. The database for the UK is then obtained by aggregation. Further work will be undertaken to ascertain whether this gives figures for the UK which vary significantly from those obtained by applying the KT method directly to UK data.

The assumption of nil migration at the oldest ages may be less robust when considering databases for each country of the UK rather than the UK as a whole, since internal migration may be more prevalent than international migration at these ages. In theory, this would not matter for producing figures at the UK level since the overall number of deaths and hence the population estimates in the UK would not be affected, just redistributed between countries within the UK.

The databases have not been constrained to provide estimates which total the official estimates for ages 90 and over other than in the final year of the database. However, for purposes where figures derived from official sources are to be used, such as official life tables, estimates which have been constrained to equal the totals would be used, being derived by applying a scaling factor to the resulting estimates so that the total over the relevant age range equals the official estimate.

Constraining the total estimates for ages 90 and over given by the KT methodology to equal the official estimates for these ages means that the database will have to be recalculated each year when the estimates for the following year are released, at least for those cohorts believed not to be extinct.

There have been slight differences in the method of calculation of the elderly populations of each individual country because of problems with data availability. The calculation methods for England and Wales combined, Scotland and Northern Ireland are described below.

England and Wales combined

An updated version of the Max Planck database calculated to 1 January 2000 has been produced. The method operates to the start of year rather than mid-year as it uses calendar year deaths data. This is the latest year for which the method can be operated; the control total for the population aged 90 and over being derived from the average of the mid-1999 and mid-2000 population estimates. The resulting population as at 1 January 2000 was then aged on to 1 January 2001 using data on deaths in the calendar year 2000 and the two populations averaged to produce estimates for mid-2000. The methodology has produced what appears to be an increasing inconsistency with published estimates at age 89 over the past few years in that the population at age 90 calculated by the KT method appears too high in relattion to the official estimates of the population aged 89. This may possibly be due to an overestimation of the numbers aged 90 and over in the official estimates. This is currently under further investigation.

Scotland

Mid-year to mid-year deaths at ages 80 and above were provided by the General Register Office for Scotland for the period from 1974 onwards in the age definition used for ageing on population estimates. The KT method was used to produce a mid-2000 age distribution. The resulting figures for males are consistent with the official estimates at age 89; the female figures suggest, if anything, that the official estimate of the numbers aged over 90 may be slightly low as the numbers aged 90 produced by the KT method look low when compared to the official estimates of the number aged 89.

Northern Ireland

Calendar year deaths have been used to calculate a database with populations at 1 January 2000. As with the England and Wales database, the 1 January 2000 population has been aged on to 1 January 2001 and the two populations averaged to produce a mid-2000 age distribution. The female figures are consistent with the official estimates at age 89, but the male figures look to have a similar inconsistency to England and Wales; however the numbers involved are much smaller than for England and Wales and smaller than for Scotland and hence may be expected to exhibit greater variability.

Results

Table 1 shows the population estimates derived for specimen years for the UK, aggregated from estimates for England and Wales, Scotland and Northern Ireland derived using the KT method. The marked increases in the numbers of both males and females in their nineties and over illustrates the importance of estimating populations at these ages. The table also shows a large increase in the number of females aged over 100 and also over age 105 since 1961. The increases for males for these age groups is lower than for females; this is partly due to factors such as war deaths.

The figures in the table also suggest that mortality rates have been improving at ages in the nineties for both males and females over the last forty years at least. For example, the number of males aged 90 has increase by 120 per cent over the period 1961 to 1991 whilst the number of males aged 100 (who are more or less the survivors from those aged 90 in 1961 and 1991) has increased by 350 per cent from 1971 to 2000. For females the corresponding increases are 260 per cent at age 90 and 460 per cent at age 100.

Tables 2 and 3 show the derived estimates for England and Wales combined, Scotland, Northern Ireland and the UK for specimen years, together with the official population estimates for the same year.

Table 1 Population at individual ages 85 and over in the UK, estimated by survival ratio method using death registrations for 1961-1999 and population estimates for mid-2000

Age	1961	1971	1981	1991	2000
Males					
90	6,225	8,535	9,437	14,192	23,980
91	5,074	6,253	7,047	10,206	19,416
92	3,523	4,459	5,209	7,023	14,307
93	2,378	3,112	3,674	4,824	10,130
94	1,546	2,137	2,508	3,338	7,000
95	865	1,402	1,637	2,261	4,736
96	519	872	1,099	1,482	3,098
97	272	544	698	985	1,945
98	156	319	459	619	1,178
99	96	173	259	370	709
100	53	89	145	215	403
101	27	63	73	128	210
102	19	36	40	77	105
103	9	19	23	42	49
104	4	7	11	19	25
105	2	1	8	11	11
106	0	1	3	7	4
107	0	1	0	3	2
108	0	0	0	1	0
109	0	0	0	0	0
110+	0	0	0	0	0
Total	20,768	28,023	32,330	45,803	87,306
Females					
90	16,203	26,732	34,557	52,016	70,090
91	12,586	20,580	27,110	40,888	61,728
92	8,932	14,987	21,015	31,327	49,556
93	6,216	10,906	15,643	23,672	38,575
94	4,540	7,828	11,309	17,479	29,263
95	3,038	5,471	8,084	12,640	21,591
96	2,002	3,603	5,603	8,910	15,521
97	1,364	2,339	3,823	6,128	10,822
98	744	1,496	2,519	4,142	7,318
99	454	905	1,636	2,708	4,832
100	276	544	991	1,669	3,072
101	151	312	571	1,013	1,860
102	78	160	299	615	1,105
103	43	87	162	350	630
104	36	42	90	194	355
105	11	17	49	103	201
106	4	11	21	50	107
107	1	7	12	27	50
108	0	3	6	12	21
109	0	1	2	5	9
110+	0	1	3	6	5
Total	56,679	96,032	133,505	203,954	316,711

Table 2 Estimates derived using survivor ratio method and official population estimates at ages 85 to 89 and ages 85+ and 90+ for England and Wales, Scotland and Northern Ireland

Age	1981		1991		1999	
	KT estimate	Official estimate	KT estimate	Official estimate	KT estimate	Official estimate
England and Wales						
Males						
85	27707	27792	44722	45196	56602	56847
86	22516	22893	36343	36679	47891	48183
87	18287	17895	29045	29207	39596	39355
88	14500	14595	22463	22834	32230	32325
89	11210	11195	17225	17308	26848	25549
90+	29067	31589	41519	42955	75029	76277
85+	123287	125959	191317	194179	278196	278536
Females						
85	80784	80197	112607	111192	120559	121260
86	68902	67997	97769	98008	106831	106689
87	57994	55698	83448	84764	93568	92864
88	48403	46498	70071	71535	81955	82027
89	39335	38398	57831	59499	74584	70792
90+	120772	125796	183888	190504	280394	283804
85+	416190	414584	605614	615502	757891	757436
Scotland						
Males						
85	2452	2471	3720	3752	4642	4596
86	2011	2042	3036	2987	3898	3983
87	1637	1639	2438	2476	3178	3185
88	1225	1250	1809	1820	2543	2560
89	968	968	1429	1431	2035	2028
90+	2433	2712	3232	3277	5262	5255
85+	10726	11082	15664	15743	21557	21607
Females						
85	7723	7686	9956	10082	10690	10782
86	6332	6187	8603	8775	9421	9463
87	5303	5156	7548	7361	8183	8171
88	4481	4329	6306	6199	7008	7058
89	3428	3371	5043	4984	5565	5931
90+	10154	10859	16013	15558	20049	19691
85+	37421	37588	53469	52959	60915	61096
Northern Ireland						
Males						
85	788	904	1010	1076	1270	1264
86	634	727	819	866	1112	1087
87	485	532	656	707	925	923
88	382	416	502	533	723	686
89	310	333	376	411	589	567
90+	830	975	1052	1142	1607	1612
85+	3429	3887	4415	4735	6226	6139
Females						
85	1894	2099	2558	2689	2988	3095
86	1592	1734	2207	2394	2626	2503
87	1324	1399	1862	1946	2303	2372
88	1061	1163	1563	1673	1997	1939
89	839	927	1291	1385	1672	1700
90+	2579	2932	4053	4360	5859	5881
85+	9289	10254	13534	14447	173445	17490

Table 3 Estimates derived using survivor ratio method and official population estimates at ages 85 to 89 and ages 85+ and 90+ for the United Kingdom

Age	1981		1991		1999	
	KT estimate	Official estimate	KT estimate	Official estimate	KT estimate	Official estimate
United Kingdom						
Males						
85	30947	31169	49452	50024	62514	62707
86	25161	25664	40198	40532	52901	53253
87	20409	20067	32139	32390	43699	43463
88	16107	16262	24774	25187	35496	35571
89	12488	12497	19030	19150	29472	28144
90+	32330	35267	45803	47374	81898	83144
85+	137442	140928	211396	214657	305979	306282
Females						
85	90401	89982	125121	123963	134237	135137
86	76826	75918	108579	109177	118878	118655
87	64621	62252	92856	94071	104054	103407
88	53945	51990	7940	79407	90960	91024
89	43602	42696	64156	65868	81824	78423
90+	133505	139589	203954	210422	306302	309376
85+	462900	462426	672617	682908	836251	836022

Table 4 shows the ratio of the KT estimates to the official estimates for the ages and years given in Tables 2 and 3. In general, for England and Wales the KT estimates for age 90 and over are lower than the official estimates from 1971 onwards. There are no official estimates for comparison purposes for this age group for earlier years. The fit for those aged 90 and over in Scotland is very good for males for the 1990s and similar to or worse than for England and Wales in the 1980s. For Scottish females, the KT estimates for the 90 and over group are lower at the beginning of the 1980s but then rise above the estimates thereafter. The KT estimates for 85 and over for each country are generally lower than or similar to the official estimates for years 1971 onwards; for 1961 to 1970 they are higher.

The fit for the age 85 and over group is better than that for the age 90 and over group in all years. This is not surprising. If the age distributions at death are correct and the assumptions made about splitting these deaths between birth cohorts are also correct, then the only difference for a given birth cohort in the actual figures for that cohort and the KT estimates is the absolute difference between these two figures in 2000. As the cohort is projected back, this absolute difference becomes smaller in percentage terms and hence the fit, in percentage terms, should improve.

Table 4 Ratio of KT estimates to official estimates

	Males			Females		
Age	1981	1991	1999	1981	1991	1999
EW						
85	0.997	0.990	0.996	1.007	1.013	0.994
86	0.984	0.991	0.994	1.013	0.998	1.001
87	1.022	0.994	1.006	1.041	0.984	1.008
88	0.993	0.984	0.997	1.041	0.980	0.999
89	1.001	0.995	1.051	1.024	0.972	1.054
90+	0.920	0.967	0.984	0.960	0.965	0.988
85+	0.979	0.985	0.999	1.004	0.984	1.001
Scotland						
85	0.992	0.991	1.010	1.005	0.988	0.991
86	0.985	1.016	0.979	1.023	0.980	0.996
87	0.999	0.985	0.998	1.029	1.025	1.001
88	0.980	0.994	0.993	1.035	1.017	0.993
89	1.000	0.999	1.003	1.017	1.012	0.938
90+	0.897	0.986	1.001	0.935	1.029	1.018
85+	0.968	0.995	0.998	0.996	1.010	0.997
NI						
85	0.869	0.939	1.005	0.903	0.951	0.965
86	0.869	0.946	1.023	0.918	0.922	1.049
87	0.909	0.928	1.002	0.947	0.957	0.971
88	0.916	0.942	1.054	0.913	0.934	1.030
89	0.927	0.915	1.039	0.905	0.932	0.984
90+	0.859	0.921	0.997	0.879	0.930	0.996
85+	0.882	0.932	1.014	0.906	0.937	0.997
UK						
85	0.993	0.989	0.997	1.005	1.009	0.993
86	0.980	0.992	0.993	1.012	0.995	1.002
87	1.017	0.992	1.005	1.038	0.987	1.006
88	0.990	0.984	0.998	1.038	0.982	0.999
89	0.999	0.994	1.047	1.021	0.974	1.043
90+	0.917	0.967	0.985	0.956	0.969	0.990
85+	0.975	0.985	0.999	1.001	0.985	1.000

7 MORTALITY RATES IN THE UK AT OLD AGES

Figures 6 and 7 show the values of the death rates, m_x, by single year of age for the UK derived from the KT database constructed for the UK for 1961 to 2000. The death rates shown are calculated by dividing deaths at the given age over a 5-year period by the sum of the mid-year populations over the same period. Figure 6 shows that mortality for males since 1976 rises gradually by age until the late 90s, but that fluctuations occur at ages 100 and higher. Up to age 100, the mortality rates for a given age are lower for successive periods. However, the results for the period 1966-70 are rather more erratic with mortality rates remaining relatively constant at ages in the late 90s before rising again but with rates at the highest ages at levels lower than in succeeding periods. One reason for this may be greater variability due to the relatively small numbers of deaths in the 1960s (the rates have not been smoothed in any way, other than by being calculated on aggregate data). A greater prevalence of age misreporting in the 1960s may also have occurred. Similar patterns occur for female mortality, again with mortality rates in the late 1960s appearing more erratic than those for later periods, although not as pronounced as for males. Excluding rates in the late 1960s, mortality rates for given ages are lower for successively later periods up to age 105.

Figure 6: Values of mx by age for five year periods - Males, UK, 1966-2000

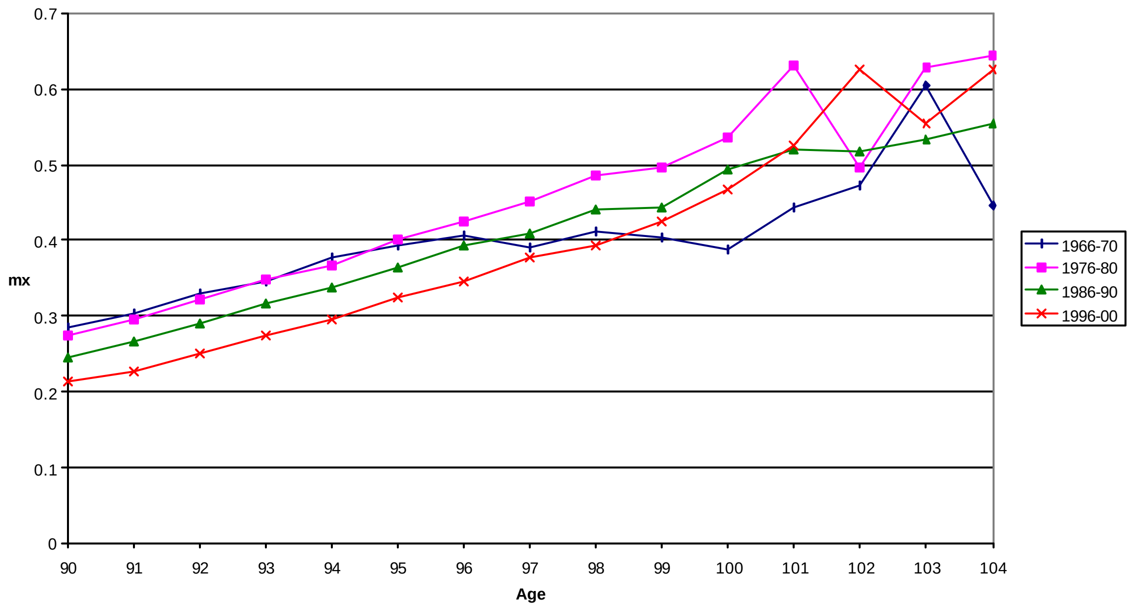


Figure 7: Values of mx by age for five year periods - Females, UK, 1966-2000

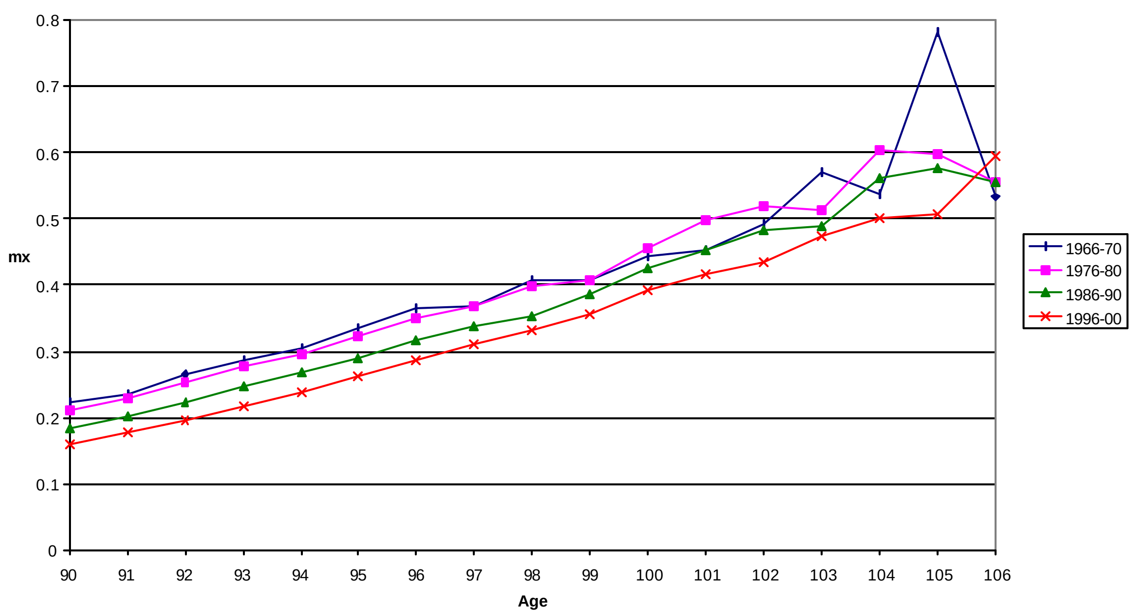


Figure 8: Values of mx by age for five year periods - Males, UK, 1961-2000

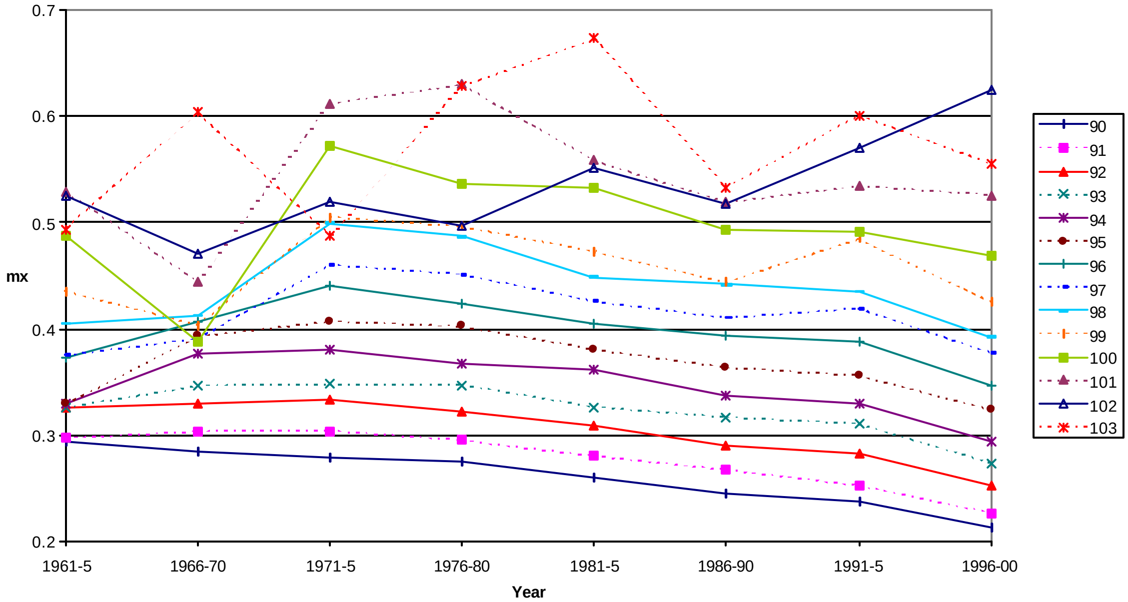
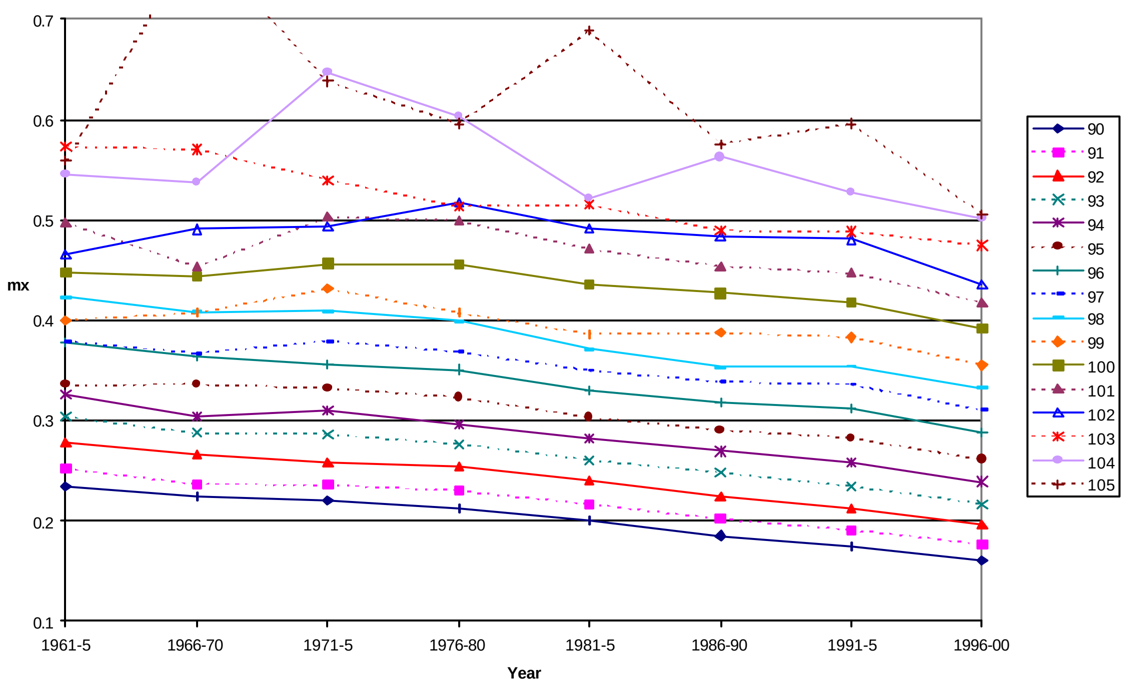


Figure 9: Values of mx by age for five year periods - Females, UK, 1961-2000



Figures 8 and 9 present the same data in a different format. It can be seen that for females, the mortality rates generally increase with age up to 101 for a given period (other than for ages 98 and 99 which cross over in 1961-5). Similar patterns exist at ages above 101 but there are more erratic movements, especially for ages 102 and 103. In general, the slopes of the lines are downwards, indicating continually falling death rates at all ages over the last twenty- five years, certainly up to age 102. Again, the change is more erratic for older ages, although even at these ages there is evidence of declining death rates. Beyond that, there appears to have been relatively little improvement in mortality rates over the period.

For males, the patterns are rather more difficult to discern, mainly because of the crossovers at various ages seen in the data for 1961-5 and in 1966-70. Death rates appear to remain static, or to increase, between 1966-70 and 1971-75. From the early 1980s, death rates at most ages up to 100 then decline over the following twenty years. Death rates for higher ages are much more erratic and there is little evidence of a general decline in death rates at ages over 100.

An analysis of the ratio of the male to female values of q_x shows that, in general, for a given year, the values of q_x for males converge towards the female values with increasing age, ie there is a decreasing differential with age. However, the data also suggest that for ages up to 100 the difference between the male and female values were widening until the early 1990s after which the trend appears to be reversing. It is possible that these are cohort effects with some cohorts generally exhibiting wider mortality differentials between males and females than others.

Tables 5 and 6 show the values of q_x for quinquennial periods derived from the values of m_x and Tables 7 and 8 show the ratio of the value for a given quinquennium to that for the preceding quinquennium at the same age.

Table 5: Values of q_x for quinquennial periods – Males, UK 1961-2000

Age	1961-5	1966-70	1971-5	1976-80	1981-5	1986-90	1991-5	1996-00
85	0.18859	0.17542	0.17340	0.17037	0.16362	0.15293	0.14156	0.13570
86	0.20803	0.19074	0.18749	0.18506	0.17601	0.16523	0.15351	0.14639
87	0.22174	0.20611	0.20048	0.19634	0.18629	0.17549	0.16615	0.15848
88	0.23112	0.21858	0.21486	0.20787	0.19983	0.18693	0.17996	0.17087
89	0.25023	0.23674	0.22854	0.21687	0.21207	0.20159	0.19343	0.18330
90	0.25657	0.24940	0.24512	0.24229	0.23040	0.21890	0.21198	0.19313
91	0.25842	0.26344	0.26397	0.25711	0.24567	0.23573	0.22411	0.20374
92	0.27966	0.28268	0.28520	0.27669	0.26741	0.25342	0.24753	0.22353
93	0.28003	0.29520	0.29598	0.29590	0.28060	0.27334	0.26871	0.24079
94	0.28315	0.31707	0.31935	0.31005	0.30547	0.28811	0.28308	0.25682
95	0.28263	0.32808	0.33805	0.33480	0.31959	0.30751	0.30209	0.27844
96	0.31399	0.33815	0.36052	0.34987	0.33656	0.32852	0.32449	0.29471
97	0.31574	0.32677	0.37411	0.36806	0.35099	0.34026	0.34653	0.31717
98	0.33663	0.34168	0.39943	0.39131	0.36630	0.36166	0.35707	0.32799
99	0.35741	0.33566	0.40327	0.39740	0.38228	0.36298	0.39010	0.35010
100	0.39204	0.32516	0.44436	0.42296	0.42036	0.39493	0.39372	0.37908
101	0.41872	0.36315	0.46841	0.47875	0.43630	0.41192	0.42161	0.41639
102	0.41547	0.38136	0.41230	0.39825	0.43189	0.41063	0.44376	0.47568
103	0.39596	0.46347	0.39198	0.47773	0.50323	0.42060	0.46212	0.43446
104	0.44215	0.36514	0.56423	0.48739	0.41135	0.43411	0.47887	0.47687
105	0.07116	0.53803	0.42831	0.64000	0.52381	0.40000	0.50000	0.57576

Table 6: Values of q_x for quinquennial periods – Females, UK 1961-2000

Age	1961-5	1966-70	1971-5	1976-80	1981-5	1986-90	1991-5	1996-00
85	0.14294	0.13211	0.12855	0.12694	0.11443	0.10354	0.09744	0.09577
86	0.15825	0.14661	0.14261	0.13975	0.12743	0.11514	0.10760	0.10682
87	0.17006	0.15769	0.15294	0.14858	0.13924	0.12639	0.11862	0.11710
88	0.18099	0.17000	0.16640	0.16019	0.15266	0.13784	0.12946	0.12850
89	0.19633	0.18556	0.18124	0.17606	0.16801	0.15346	0.14221	0.14056
90	0.21008	0.20170	0.19857	0.19178	0.18196	0.16939	0.15987	0.14833
91	0.22376	0.21144	0.21094	0.20619	0.19559	0.18315	0.17440	0.16238
92	0.24385	0.23434	0.22914	0.22579	0.21412	0.20168	0.19167	0.17879
93	0.26374	0.25128	0.25033	0.24307	0.23054	0.22065	0.20990	0.19563
94	0.27976	0.26401	0.26891	0.25783	0.24774	0.23720	0.22906	0.21371
95	0.28712	0.28778	0.28493	0.27815	0.26300	0.25377	0.24744	0.23095
96	0.31734	0.30812	0.30245	0.29854	0.28344	0.27418	0.26988	0.25136
97	0.31873	0.31001	0.31892	0.31110	0.29782	0.28957	0.28751	0.26851
98	0.34914	0.33894	0.33936	0.33263	0.31283	0.29989	0.30058	0.28519
99	0.33339	0.33843	0.35482	0.33832	0.32372	0.32463	0.32139	0.30141
100	0.36568	0.36352	0.37162	0.37064	0.35752	0.35166	0.34512	0.32781
101	0.39829	0.36937	0.40186	0.39946	0.38116	0.36994	0.36526	0.34544
102	0.37786	0.39402	0.39558	0.41120	0.39440	0.38925	0.38755	0.35796
103	0.44546	0.44382	0.42508	0.40851	0.40960	0.39325	0.39249	0.38367
104	0.42843	0.42381	0.48863	0.46302	0.41384	0.43889	0.41717	0.40126
105	0.43711	0.56216	0.48374	0.45920	0.51226	0.44694	0.45912	0.40389

Table 7: Ratio of q_x for quinquennial periods to preceding quinquennial period
Males, UK 1966-2000

Age	1966-70	1971-5	1976-80	1981-5	1986-90	1991-5	1996-00

85	0.930	0.988	0.983	0.960	0.935	0.926	0.959
86	0.917	0.983	0.987	0.951	0.939	0.929	0.954
87	0.930	0.973	0.979	0.949	0.942	0.947	0.954
88	0.946	0.983	0.967	0.961	0.935	0.963	0.950
89	0.946	0.965	0.949	0.978	0.951	0.960	0.948
90	0.972	0.983	0.988	0.951	0.950	0.968	0.911
91	1.019	1.002	0.974	0.956	0.960	0.951	0.909
92	1.011	1.009	0.970	0.966	0.948	0.977	0.903
93	1.054	1.003	1.000	0.948	0.974	0.983	0.896
94	1.120	1.007	0.971	0.985	0.943	0.983	0.907
95	1.161	1.030	0.990	0.955	0.962	0.982	0.922
96	1.077	1.066	0.970	0.962	0.976	0.988	0.908
97	1.035	1.145	0.984	0.954	0.969	1.018	0.915
98	1.015	1.169	0.980	0.936	0.987	0.987	0.919
99	0.939	1.201	0.985	0.962	0.950	1.075	0.897
100	0.829	1.367	0.952	0.994	0.940	0.997	0.963
101	0.867	1.290	1.022	0.911	0.944	1.024	0.988
102	0.918	1.081	0.966	1.084	0.951	1.081	1.072
103	1.171	0.846	1.219	1.053	0.836	1.099	0.940
104	0.826	1.545	0.864	0.844	1.055	1.103	0.996
105	7.561	0.796	1.494	0.818	0.764	1.250	1.152

Table 8: Ratio of q_x for quinquennial periods to preceding quinquennial period
Females, UK 1966-2000

Age	1966-70	1971-5	1976-80	1981-5	1986-90	1991-5	1996-00
85	0.924	0.973	0.987	0.901	0.905	0.941	0.983
86	0.926	0.973	0.980	0.912	0.904	0.934	0.993
87	0.927	0.970	0.971	0.937	0.908	0.938	0.987
88	0.939	0.979	0.963	0.953	0.903	0.939	0.993
89	0.945	0.977	0.971	0.954	0.913	0.927	0.988
90	0.960	0.984	0.966	0.949	0.931	0.944	0.928
91	0.945	0.998	0.978	0.949	0.936	0.952	0.931
92	0.961	0.978	0.985	0.948	0.942	0.950	0.933
93	0.953	0.996	0.971	0.948	0.957	0.951	0.932
94	0.944	1.019	0.959	0.961	0.957	0.966	0.933
95	1.002	0.990	0.976	0.946	0.965	0.975	0.933
96	0.971	0.982	0.987	0.949	0.967	0.984	0.931
97	0.973	1.029	0.975	0.957	0.972	0.993	0.934
98	0.971	1.001	0.980	0.940	0.959	1.002	0.949
99	1.015	1.048	0.953	0.957	1.003	0.990	0.938
100	0.994	1.022	0.997	0.965	0.984	0.981	0.950
101	0.927	1.088	0.994	0.954	0.971	0.987	0.946
102	1.043	1.004	1.039	0.959	0.987	0.996	0.924
103	0.996	0.958	0.961	1.003	0.960	0.998	0.978
104	0.989	1.153	0.948	0.894	1.061	0.951	0.962
105	1.286	0.861	0.949	1.116	0.872	1.027	0.880

8 PROJECTING MORTALITY RATES AT THE OLDEST AGES

Currently, projections of mortality rates for the oldest ages in the UK national population projections are carried out using the same methodology as used for projecting rates at younger ages. This method involves elements of extrapolation and target setting.[8]

At the time that the Government Actuary's Department agrees the assumptions for the projections with the Registrars General, crude mortality rates by age and sex are generally known only for the years up to and including the year preceding the base year of the projection. Mortality rates for the base year are estimated by analysing trends in mortality rates by age and sex over the previous forty years and extrapolating forward for one year to the base year. This extrapolation is also used to determine a set of improvement factors by age and sex for mortality rates in the base year of the projections. Target improvement rates for a future year are also set – for the 2000-based projections, it is assumed that the rate of mortality improvement will be 0.75 per cent a year in 2025 at all ages for both males and females. Mortality improvement factors for each sex by age and calendar year for years between the base year of the projections and the target year are obtained by interpolation between the improvement factors assumed for the base year and those assumed for the target year assuming that the rate of decline (or increase) from the improvement factors in the base year to those assumed for the target year will be greater in the earlier years of the projection.

The historic data for cohorts born before 1947 shows evidence of differential rates of improvement in mortality between generations. For example, mortality rates for generations born around 1931 are still improving at faster rates than earlier and later generations. There is also evidence for similar cohort effects for those born in years before 1931. It is not known whether these outcomes result from something inherent within the generations concerned (for example, differences in childhood environment, growing up during the war years), or whether this is merely the result of various period effects that happen to have produced greater improvements for these generations. Thus, for cohorts born before 1947, the interpolation to determine the annual improvement factors by age and calendar year is carried out along a cohort, rather than along the year of age.

At one level, the assumptions made for projecting rates at very old ages will have little effect on the overall population numbers and hence it could be argued that a similar method should be used here as for other ages. However, there is always particular interest in the projected numbers of centenarians when projections are published. A methodology which produced rapidly varying estimates between projections may cast some doubt on the whole projection process even though such estimates are, by nature, likely to be more variable than estimates covering younger ages.

Several countries produce population projections which involve the adoption of target assumptions in target years for projecting mortality and this would seem a reasonable methodology for use at the oldest ages. Other possible methods include extrapolation of current rates of improvement into the future, for example using a Lee-Carter methodology (Lee 2000) or attempting to fit mathematical curves to the data and extrapolating the parameters of the curve. The latter can be difficult, however, and has not proved amenable to projecting mortality rates in the UK. There are problems in trying to fit curves to mortality rates over the whole range of ages which do not involve a large number of parameters. Even where this can be done, there is no guarantee that it will prove easy to project the values of these parameters to produce reasonable future mortality rates. For these reasons, such a method has been rejected for use in projecting mortality rates at all ages for the UK. The difficulties may be eased if curves are fitted to a subgroup comprising the oldest ages only, since fewer parameters may be needed. There is a growing body of evidence as to which curves may be most suitable for this purpose (eg the logistic curve). However, if such a method is used only for the oldest ages, problems will inevitably arise in future years of the projections at ages where the method is joined to that chosen for younger ages. (Such problems also exist in constructing life tables, but the problems arising in attempting to maintain reasonable continuity at the ages where the methods join only arises for a very small number of years, rather than the several decades covered in a set of population projections.) Similar problems may arise if an extrapolatory method is used for this particular age group. The straightforward application of an extrapolation method may produce mortality rates that reduce with increasing age, or which increase indefinitely, which may be considered unlikely by most demographers.

The review of the methodology for projecting mortality rates in the UK national projections recommended that the methodology currently in use be retained but that ways of more clearly relating the targeting of the rates of mortality improvement to available data and other relevant evidence should be considered. For projecting mortality at old ages, consideration needs to be given to whether the same target improvement factors should be assumed as for younger ages. The database of historical mortality rates discussed earlier in this paper is intended to provide the basis for analysis of past mortality trends at the oldest ages. The methods discussed above for projecting mortality rates could all play a role in setting the assumptions. Suitable target rates of improvement might be derived from consideration of the results of extrapolating recent levels of improvement, fitting curves to derived mortality rates at these ages and extrapolating the parameters, consulting demographic and medical experts and considering the results of recent research and practical developments.

Given the relatively small improvements which have occurred in mortality rates at the oldest ages in comparison with the improvements at younger ages, one of the fundamental issues is whether this general feature will continue in future or whether we can reasonably project more dramatic changes at older ages.

9 DISCUSSION

Population estimates and mortality rates are required at the oldest ages for the United Kingdom and constituent countries for constructing life tables and for carrying out national population projections. However, whilst data on deaths are available at all ages, population numbers are not available by year of age for ages 90 and above. Various methods have been used over the last decade to estimate these figures. Recently, this work has focussed on the methodologies proposed by Kannisto and Thatcher. Their methods have been used to derive a database of population estimates at ages over 90 (or 85 for earlier years) for the UK and constituent countries.

This database appears to provide good population estimates for the age group 85 and over, compared to the official population estimates, and also for the age group 90 and over, especially for more recent years. For work carried out using official demographic data, it has been decided to use the officially published figures as far as possible. This means that the official estimates will be used for individual ages up to 89, with estimates derived using the KT methodology for older ages. These would be used for official life tables and for deriving the starting population numbers for the base year of a set of national population projections. The mortality rates resulting from the UK database constructed back to 1961 will be analysed when setting assumptions for future population projections.

However, in constructing the database, problems have occurred at the ages where the official estimates and the KT estimates join. For example, for England and Wales, the latest calculations from the KT method imply a figure for age 89 at 1 January 1999 that does not compare well to the age 89 figures at 1 January 1999 calculated by averaging the two adjacent estimate figures. There are three main possibilities for this:

- The KT method does not produce the right age distribution
- There is a problem with the population estimates at age 89
- There is a problem with the population estimates at age 90+.

Each of these possibilities is being investigated. While the KT method is obviously an approximation, it has been shown to be robust by the work that has been carried out at the Max Planck Institute for Demographic Research. There are parameters to be chosen in carrying out the method, chiefly over how many cohorts and how many years back the survival ratios are operated. However, experiments varying these parameters do not appear to provide any great improvement to the discontinuity problem above.

The estimates at age 89 are the result of ageing on those aged 80 and 81 in the 1991 census. There was very little adjustment at ages 79, 80 and 81 for 1990 after the census rebasing, suggesting that the 1991 census data at these ages provides a reasonably good starting point.

The operation of the KT method controlled to the overall population of 90 and over given by the estimates is dependent on the assumption that the errors in the individual age data underlying the total (which are the reason why they themselves are not used) average out and the overall 90 and over estimate gives a good approximation. It appears that as one moves further from the 1991 census base this may not be true for the England and Wales age 90 and over population estimate. Extending the KT method back to age 85 implies that the population aged 90 and over is too high. Each year from 1991 a further potential error is added to the 90 and over total. Of course by the year 2000 any errors in the population aged 90 and over are an accumulation of errors from age 81 in 1991. However, it will be necessary to wait for the results of the 2001 census and the effects of any rebasing of the estimates back to 1991 to see whether there are large changes in the estimates for those aged 90 and over.

10 CONCLUSIONS

Mortality rates in the UK have been falling over the twentieth century. However, there is a lack of data to derive mortality rates by single year of age at ages 85 and over (or 90 and over in more recent years of the last century) to analyse the rates of reduction at these ages. Data are available from the historic English and Scottish Life Tables. However, mortality rates derived at the oldest ages in the Tables suffer from unreliability in the estimated numbers at these ages as reported in the census on which the national Life Tables before the 1980-82 series are based. The differing methodologies adopted for graduating mortality rates at the oldest ages also make comparisons at these ages between Life Tables difficult.

The unreliability of census data for ages 90 and over has also meant that official population estimates are not published by individual year of age above age 89. However, the growing numbers aged 90 and over in the UK population have meant that reliable estimates by single year of age are required for this age group. The paper describes recent work carried out by the UK Government Actuary's Department to construct a database of population estimates and of historical mortality rates for the UK by each year of age from 1961 onwards. Further work is required to check the results and to investigate discontinuities between the estimates derived using the KT methodology and the official population estimates.

Section 7 of the paper shows that mortality rates derived from the population estimates in thia database and the registered numbers of deaths by age suggest that mortality is declining at very old ages, at least up to age 100 for males and to age 105 for females. However, the picture beyond these ages is not clear cut, partly because the numbers of deaths at these ages are still very small.

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Notes

1. Thatcher A R (1994) Centenarians: 1991 estimates. *Population Trends* 75, The Stationery Office (TSO).
2. A description of some of these checks is given in the Office for National Statistics reference volumes *Mortality Statistics by Cause*, Series DH2.
3. For further information on the registration of deaths in the UK, see Recording of birth and deaths in the countries of the United Kingdom. Devis T. *Health Statistics Quarterly* 6 (2000), TSO
4. In the nineteenth century, Wales was regarded as a region of England.
5. See Thatcher A R (1981) Centenarians *Population Trends* 25, TSO and the editorial Centenarians: 1981 estimate *Population Trends* 38, TSO (1984)
6. National Population Projections: Review of methodology for projecting mortality. *National Statistics Quality Review Series.* TSO (forthcoming)
7. Thatcher A R and Kannisto V (2000) The survivor ratio method
8. For more details of methodology adopted see *National population projections: 1998-based* (2000) ONS series PP2 no.22 TSO.

References and Bibliography

Andreev K (1999). Demographic Surfaces: Estimation, assessment and presentation with application to Danish mortality 1835-1995.

Boleslawski L and Tabeau E (2001). Comparing theoretical age patterns of mortality beyond the age of 80. Chapter 6 in E Tabeau, A van den Berg Jeths, C Heathcote (eds.): Forecasting mortality in developed countries: Insights from a statistical, demographic and epidemiological perspective. *European Studies of Population* (ESPO) Vol 9. Kluwer Academic Publishers.

English Life Tables Numbers 1 to 15. TSO.

Das Gupta P (1990). Reconstruction of the age distribution of the extreme aged in the 1980 census by the method of extinct generations. Paper presented at the 1990 Joint Statistical Meetings, Anaheim, California.

Humphrey G T (1970). Mortality at oldest ages. *Journal of the Institute of Actuaries* 96 pp105-119

Kannisto (1988). On the survival of centenarians and the span of life. *Population Studies* 42 pp 389-406.

Kannisto V, Lauritsen J, Thatcher A R and Vaupel J W (1994). Reductions in mortality at advanced ages: several decades of evidence from 27 countries. *Population Development Review* 20 pp739-810.

Lee R (2000). The Lee-Carter method for forecasting mortality, with various extensions and applications. *North American Actuarial Journal* Vol 4 No 1.

Thatcher A R (1992). Trends in numbers and mortality at high ages in England and Wales. *Population Studies* 46 pp411-426

Thatcher A R (1994). Centenarians: 1991 estimates. *Population Trends* 75, TSO.

Thatcher A R, Kannisto V and Vaupel J W (1998). The force of morality at ages 80 to 120. Odense: Odense University Press.

Thatcher A R (1999). The demography of centenarians in England and Wales, *Population Trends* 96, TSO.

Thatcher A R (1999). The long-term pattern of adult mortality and the highest attained age. *Journal of the Royal Statistical Society* Vol 162, Part 1, pp5-43

Thatcher A R and Kannisto V (2000). The survivor ratio method

Vincent P (1951). La mortalité des vieillards. *Population* No 6

Quality of the reporting of 'age at death' in death registration in Northern Ireland (2000) In Brief, *Health Statistics Quarterly* No 5

APPENDIX A

PUBLISHED POPULATION ESTIMATES FOR CONSTITUENT COUNTRIES OF THE UNITED KINGDOM

England & Wales combined; Scotland

Period	Published data on population estimates
Pre-1959	Prior to 1959, population estimates usually published in 5-year age groups, except for the data provided by a census
1959 to 1970	Population estimates available by sex and single year of age up to 84, together with a totals figure for age 85 and over
1971 onwards	Population estimates available by sex and single year of age up to 89, together with a totals figure for age 90 and over

Northern Ireland

Period	Published data on population estimates
Pre-1959	Prior to 1959, population estimates usually published in 5-year age groups, except for the data provided by a census
1959 to 1970	Unpublished records are available with individual age data, often by single year of age, for people up to 95 and then by aggregate total for the 95-plus. Data for 1966 is available only in 5-year age bands.
1971 to 1980	Population estimates available by sex and single year of age up to 89, together with a totals figure for age 90 and over
1981 to 1989	Population estimates available by sex and single year of age up to 84, together with a totals figure for age 85 and over[1]
1990 onwards	Population estimates available by sex and single year of age up to 89, together with a totals figure for age 90 and over

[1]Previously, data by single year of age for the period 1981 to 1990 were available up to the age of 89, but when revisions were made to the NI population estimates for these years, revised figures were produced by age only for people under 85