

# Report:

## Decennial Life Tables (2000–02)

### Introduction

Graduated period life tables for males and for females have been constructed based on the mortality experience of the population of England and Wales during the three years 2000, 2001 and 2002. These tables, (known as the English Life Tables and denoted briefly as ELT 16), are the sixteenth in a series known as the English Life Tables which are associated with decennial population censuses, beginning with the census of 1841. These period life tables show the increasing longevity of the population of England and Wales over a long period, and they can be compared with the experience of other countries and other groups of people.

Similar life tables have also been prepared for England, Wales, Scotland and Northern Ireland based on data for 2000–02. Whilst Scottish Life Tables have also been produced since the 1871 census, this is the first time that graduated life tables have been produced for each of the constituent countries of the United Kingdom as well as for England and Wales combined. However, ungraduated life tables – the Interim Life Tables<sup>1</sup> – have been produced and published annually for each country as well as England and Wales, Great Britain and the UK, starting with the period 1980–82. This is described in more detail later in the report.

### Data and construction of the tables

The Decennial Life Tables for 2000–02 are based on data centred on the census year, 2001. A three-year period is normally of sufficient length to smooth out most of the effect if the mortality experience of the census year itself happens not to be typical of the general level of mortality at the beginning of the decade.

Apart from the calculation of the rates for mortality during the first year of life and at ages 90 and over, the average population numbers at each age during the three calendar years 2000 to 2002 were taken as the mean of the mid-year estimates published by the Office for National Statistics (ONS), the General Register Office for Scotland (GROS), or the Northern Ireland Statistics and Research Agency (NISRA) for those years, which take into account the results from the 2001 census and later revisions. Single year of age population estimates for ages 90 and over have not been published until recently, partly because of the

problems of age mis-statement of elderly people in censuses. Population estimates for these ages have been made using a methodology drawing on work carried out on mortality at high ages in England and Wales by A R Thatcher, V Kannisto and K Andreev<sup>2</sup>.

Crude rates of mortality for each age (denoted by  $m_x$ ) were obtained by dividing the total deaths in each of the three calendar years 2000, 2001 and 2002 by an exposed-to-risk derived from the mid-year population estimates for the three years added together. These crude death rates are not always suitable as the basis for a standard life table because they tend to vary erratically from age to age owing to the small numbers of deaths involved, particularly in childhood and at very advanced ages. Errors are also present in the data because no census is perfectly accurate or complete and neither are the mid-year estimates of the population. Errors arising because of the small numbers of deaths, and, to some extent, other types of error, can be reduced by a process of smoothing these crude death rates.

For the Decennial Life Tables, the intention of this smoothing (or ‘graduation’) is to replace the crude rates by a series of graduated rates which, while forming a smooth progression over the whole age range covered, still preserves the general shape of the mortality curve. Various means of carrying out this smoothing have been applied in constructing the English and Scottish Life Tables in the past. For the current graduation, a methodology developed by Dr. Vladimir Kaishev, Professor Steven Haberman and Dimitrina Dimitrova of the Cass Business School, City University, London has been used. This follows a variable-knot spline regression approach and uses a weighted least squares version of the GeD spline regression method proposed by Kaishev *et al*<sup>3,4</sup>. The method determines the degree of the spline fit and also the number and position of its knots, according to an optimality criterion. Applying this method produces quadratic spline fits of the logs of the crude mortality rates, which are not overly parameterized and can be evaluated, for any arbitrary age, using a calculator. The resulting graduated death rates ( $m_x$ ) are then converted into initial rates of mortality,  $q_x$ , which give the probability of a person aged exactly  $x$  dying before reaching age  $(x + 1)$ .

In order to extrapolate the spline fits beyond the highest ages for which crude mortality rates have been collected and to close the life tables at a limiting age  $\omega = 121$ , the spline fits were constrained at age 120

so that  $m_{120} = 2$ . The latter is obtained by setting  $q_{120} = 1$  and using the approximation  $q_x = m_x / (1 + 0.5m_x)$  which holds for  $x = 120$  if a uniform distribution of deaths is assumed over the age interval [120, 121]. Different formulae are used for converting  $m_x$  values to  $q_x$  values for ages below 100.

Since the observed mortality rate is quite high in the first year of life and drops sharply in the next year, this creates a severe constraint on the fits at the first year of age. In order to avoid this difficulty, data for age 0 is excluded from the spline fitting and the values of  $q_0$  were obtained directly from the records of births and deaths at age 0 in the years 2000 to 2002. A detailed description of the methodology is available on the ONS website<sup>5</sup>.

### Life Tables

The following tables provide data for selected ages extracted from the full set of Decennial Life Tables for England and Wales, England, Wales, Scotland and Northern Ireland.

Definitions of the symbols used in the Life Tables and elsewhere and a brief description of their calculation are given in **Box one**.

Data files of the life tables containing a record of the mortality rates at each age, calculated as accurately as possible from death registration data by occurrence and population numbers, and the resulting graduated

**Table 1** Data for selected ages from English Life Tables 16, 2000–02, England and Wales

Age	Males			Females		
	$l_x$	$q_x$	$e_x^o$	$l_x$	$q_x$	$e_x^o$
0	100000	0.00598	75.958	100000	0.00484	80.585
10	99242	0.00012	66.528	99383	0.00010	71.077
20	98908	0.00078	56.730	99210	0.00029	61.190
30	98091	0.00095	47.160	98893	0.00042	51.369
40	96936	0.00158	37.657	98273	0.00099	41.657
50	94587	0.00396	28.449	96719	0.00260	32.234
60	88904	0.01052	19.899	92905	0.00633	23.323
70	74905	0.02886	12.556	83777	0.01753	15.239
80	45701	0.07821	7.107	61495	0.05194	8.714
90	12078	0.19051	3.695	23859	0.15264	4.303
100	474	0.38966	1.821	1633	0.33525	2.152

**Table 2** Data for selected ages from Scottish Life Tables, 2000–02

Age	Males			Females		
	$l_x$	$q_x$	$e_x^o$	$l_x$	$q_x$	$e_x^o$
0	100000	0.00620	73.330	100000	0.00485	78.790
10	99210	0.00014	63.903	99382	0.00009	69.272
20	98779	0.00127	54.151	99158	0.00039	59.413
30	97428	0.00158	44.830	98730	0.00054	49.649
40	95696	0.00228	35.546	97971	0.00124	39.989
50	92546	0.00526	26.563	95995	0.00329	30.692
60	84812	0.01444	18.459	91192	0.00822	22.009
70	67615	0.03561	11.740	79872	0.02178	14.321
80	37869	0.08901	6.788	55259	0.06103	8.222
90	9286	0.19509	3.634	19332	0.16029	4.220
100	353	0.39381	1.789	1241	0.35206	2.021

**Table 3** Data for selected ages from Northern Ireland Life Tables, 2000–02

Age	Males			Females		
	$l_x$	$q_x$	$e_x^o$	$l_x$	$q_x$	$e_x^o$
0	100000	0.00576	75.244	100000	0.00479	80.153
10	99251	0.00016	65.801	99405	0.00009	70.625
20	98754	0.00097	56.099	99252	0.00028	60.725
30	97734	0.00103	46.632	98948	0.00038	50.895
40	96577	0.00162	37.126	98371	0.00100	41.160
50	94159	0.00410	27.932	96686	0.00279	31.776
60	88064	0.01116	19.466	92769	0.00652	22.878
70	73020	0.03109	12.303	83175	0.01873	14.850
80	43601	0.08158	6.963	59905	0.05615	8.424
90	11224	0.19778	3.515	21926	0.15912	4.189
100	333	0.43306	1.585	1324	0.36386	1.943

**Table 4** Data for selected ages from Decennial Life Tables for England, 2000–02

Age	Males			Females		
	$l_x$	$q_x$	$e_x^o$	$l_x$	$q_x$	$e_x^o$
0	100000	0.00600	75.990	100000	0.00486	80.621
10	99239	0.00012	66.562	99381	0.00010	71.115
20	98903	0.00079	56.765	99206	0.00028	61.230
30	98094	0.00095	47.192	98893	0.00041	51.407
40	96949	0.00157	37.685	98277	0.00098	41.693
50	94600	0.00395	28.478	96730	0.00260	32.267
60	88927	0.01047	19.926	92925	0.00633	23.355
70	74980	0.02868	12.575	83844	0.01744	15.263
80	45765	0.07852	7.122	61613	0.05193	8.729
90	12140	0.19261	3.689	23904	0.15428	4.319
100	490	0.38491	1.861	1659	0.33988	2.121

**Table 5** Data for selected ages from Decennial Life Tables for Wales, 2000–02

Age	Males			Females		
	$l_x$	$q_x$	$e_x^o$	$l_x$	$q_x$	$e_x^o$
0	100000	0.00561	75.431	100000	0.00446	80.125
10	99287	0.00010	65.964	99447	0.00009	70.564
20	98934	0.00086	56.175	99310	0.00027	60.653
30	97946	0.00113	46.689	98965	0.00044	50.845
40	96651	0.00172	37.243	98320	0.00110	41.141
50	94255	0.00393	28.046	96646	0.00259	31.755
60	88439	0.01070	19.510	92739	0.00690	22.849
70	73491	0.03137	12.311	82720	0.01906	14.921
80	43712	0.08121	7.031	59674	0.05537	8.512
90	11327	0.19328	3.710	22132	0.15599	4.292
100	494	0.37257	1.915	1488	0.35115	2.020

set of those rates and life tables, together with an explanation of the methodology used to graduate these rates, are available on the ONS<sup>5</sup>, GROS<sup>6</sup> and NISRA<sup>7</sup> websites.

### Expectation of Life

One way of illustrating the reductions in death rates is to show the increase in expectation of life at birth, calculating it either from the death

# Box one

## Definitions

$l_x$  are the number of survivors to age  $x$  of 100,000 live births of the same sex for a given country who subsequently experience mortality similar to that of the population of that sex in that country in 2000–02.

$d_x$  are the number dying between age  $x$  and  $(x + 1)$ , described similarly to  $l_x$ , that is  $l_x - l_{x+1}$ .

$q_x$  is the initial mortality rate between age  $x$  and  $(x + 1)$ , that is,  $d_x/l_x$ .

$\mu_x$  is the force of mortality at age  $x$ , that is,  $-\frac{1}{l_x} \frac{dl_x}{dx}$

and calculated as

$$\begin{aligned} & (11l_x - 18l_{x+1} + 9l_{x+2} - 2l_{x+3})/6l_x && \text{if } x = 1 \text{ or } 2, \text{ and} \\ & (-l_{x-2} + 8l_{x-1} - 8l_{x+1} + l_{x+2})/12l_x && \text{otherwise.} \end{aligned}$$

$e_x^o$  is the average expectation of life, the average number of years that those aged  $x$  will live thereafter, and calculated as

$$e_x^o = \sum_{t=1}^{w-x-1} \frac{l_{x+t}}{l_x} + \frac{1}{2} - \frac{1}{12} \mu_x$$

$\omega$  is the earliest age by which all the survivors are assumed to have died, so that  $q_{\omega-1}$  is assumed to equal 1. For each country,  $\omega$  is assumed to equal 121.

rates of particular calendar years, or taking the rates over time applicable to people born in a particular year. The latter can, however, only be done for generations not yet extinct by making assumptions about future death rates.

The data presented in the Decennial Life Tables represents a snapshot of the mortality of the community at a particular point in time; they do

not purport to show the likely experience of any particular generation. However, in spite of this, expectations of life based on such period measures (period expectations of life) form a convenient summary measure of the overall effects of changes in mortality. **Table 6** sets out the period expectations of life for England and Wales at various ages for mortality based on the years 1910–12 and at twenty year intervals thereafter until 1970–72, together with those for 1980–82, 1990–92 and 2000–02. The figures are compiled from the English Life Tables derived from the mortality experience in these periods.

Over the 90 years covered by Table 6 the expectation of life at birth, measured in this way, has increased by almost 24.5 years for a boy and by just over 25 years for a girl. A large part of the improvement since 1911 has been due to reductions in mortality in infancy and childhood but this is not the only cause, as is shown by the fact that the expectation for a man aged 20 has increased by 12.5 years and for a women aged 20 by just over 14 years. At age 60 the increase in expectation is just over 6 years for males and almost 8 years for females. The above expectations of life, and the corresponding life tables, represent a secular cross-section of the experience of those born during a century or so prior to the respective periods.

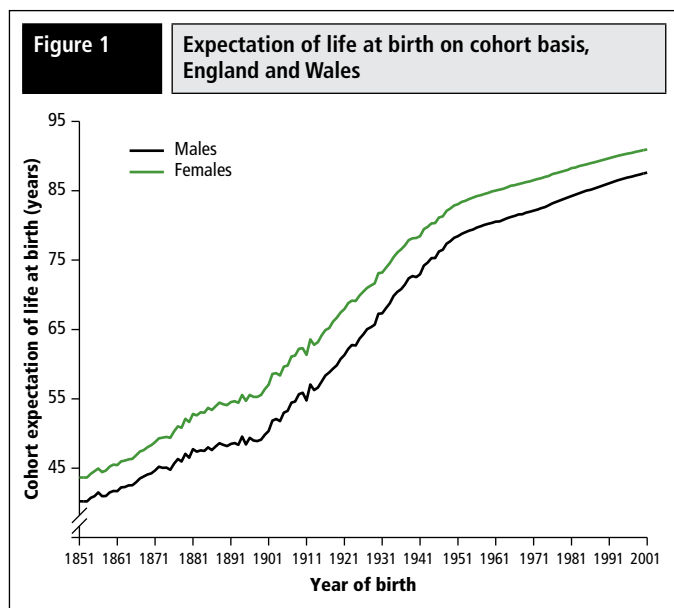
It is also possible to calculate expectations of life applicable to people born in a particular year (often referred to as cohort expectations of life). **Figure 1** shows the expectations of life at birth calculated on a cohort basis based on estimated historical or projected mortality rates for each year. In order to estimate cohort expectation of life, mortality rates for years beyond 2006 have been taken from the 2006-based projections for England and Wales. The chart shows, for example, that the average number of years that a new-born boy could expect to live rose from 40 in 1851 to about 87.6 in 2001. Males born in 1851 had only a 65 per cent chance of reaching age 20 and those reaching this age on average lived only to age 60. Of the generation born in 1971 only 3 per cent failed to reach age 20. The cohort expectation of life of 87.6 years for a boy born in 2001 is calculated on the assumption that death rates will continue to fall, but at a diminishing rate.

The cohort expectation of life at birth is longer than the period expectation of life for all years of birth since 1851 for both males and females. This is because the cohort calculation takes into account changes

**Table 6**

**Period expectation of life ( $e^o$ ): England and Wales 1910–12 to 2000–02**

Age x	ELT8 1910–12	ELT10 1930–32	ELT11 1950–52	ELT12 1960–62	ELT13 1970–72	ELT14 1980–82	ELT15 1990–92	ELT16 2000–02
<b>Males</b>								
0	51.50	58.74	66.42	68.09	69.00	71.04	73.41	75.96
10	53.08	55.79	59.24	60.21	60.74	62.19	64.20	66.53
20	44.21	46.81	49.64	50.57	51.08	52.50	54.45	56.73
30	35.81	38.21	40.27	41.06	41.51	42.90	44.88	47.16
40	27.74	29.62	30.98	31.62	32.01	33.34	35.35	37.66
50	20.29	21.60	22.23	22.68	23.11	24.26	26.16	28.45
60	13.78	14.43	14.79	15.06	15.41	16.38	17.85	19.90
70	8.53	8.62	9.00	9.29	9.50	10.12	11.19	12.56
<b>Females</b>								
0	55.35	62.88	71.54	74.00	75.25	77.00	78.96	80.59
10	55.91	58.87	63.87	65.77	66.71	67.97	69.61	71.08
20	47.10	49.88	54.17	55.95	56.89	58.12	59.75	61.19
30	38.54	41.22	44.68	46.23	47.13	48.34	49.94	51.37
40	30.30	32.55	35.32	36.69	37.52	38.67	40.24	41.66
50	22.51	24.18	26.34	27.57	28.41	29.39	30.85	32.23
60	15.48	16.50	18.07	19.11	19.98	20.89	22.08	23.32
70	09.58	10.02	10.97	11.78	12.56	13.41	14.49	15.24



**Table 7** Expectation of life (allowing for future improvement in mortality) for selected ages in 2001, England and Wales

Age in 2001	Expectation of life	
	Male	Female
0	87.6	91.0
10	77.0	80.4
20	65.8	69.4
30	55.0	58.5
40	44.4	47.8
50	34.3	37.3
60	24.3	27.2
70	14.7	17.0
80	7.7	9.1

in the actual (or projected) mortality rates in years succeeding the year of birth whereas the period calculation uses mortality rates applicable in the year under consideration. Since, in general, mortality rates have been improving in successive years at most ages and are projected to continue to do so, the cohort expectation of life assumes lower mortality than the period expectation of life.

**Table 7** shows the cohort expectations of life in 2001 for various attained ages in 2001 assuming that the future improvements in mortality assumed in the 2006-based population projections for England and Wales actually occur.

### Interim Life Tables

The English and Scottish Life Tables provide a valuable time series which can be used to monitor trends in mortality in England and Wales and in Scotland over a long period of time. However, these tables are only calculated once every ten years and the graduation process carried out is usually complex and has changed over time. The Office for National Statistics also produces annual life tables, known as Interim Life Tables, for each constituent country of the United Kingdom, together with life tables for England and Wales combined, Great Britain, and the United Kingdom as a whole. These are based on mortality data for three consecutive calendar years combined (as for the Decennial Life Tables). In order to produce these interim life tables quickly, once the relevant data is available, the mortality rates used in these tables are not graduated. These interim life tables are available on the ONS and the Government Actuary's Department websites<sup>5</sup>.

### References

- Office for National Statistics (2008). Latest information on life expectancy available at: [www.statistics.gov.uk/cci/nugget.asp?id=168](http://www.statistics.gov.uk/cci/nugget.asp?id=168)
- Thatcher A R, Kannisto V and Andreev K (2002). 'The survivor ratio method for estimating numbers at high ages'. *Demography* 6.
- Kaishev V K, Dimitrova D S, Haberman S and Verrall R (2006). Geometrically designed, variable knot regression splines: Asymptotics and inference. Statistical Research paper 28, Cass Business School, City University, London
- Kaishev V K, Dimitrova D S, Haberman S and Verrall R (2006). Geometrically designed, variable knot regression splines: Variation diminishing optimality of knots. Statistical Research paper 29, Cass Business School, City University, London
- Office for National Statistics. Latest information on Decennial life tables are available at: [www.statistics.gov.uk/StatBase/Product.asp?vlnk=333](http://www.statistics.gov.uk/StatBase/Product.asp?vlnk=333)
- General Register Office for Scotland. Latest data available at: [www.gro-scotland.gov.uk/statistics/publications-and-data/life-expectancy/life-expectancy-at-scotland-level.html](http://www.gro-scotland.gov.uk/statistics/publications-and-data/life-expectancy/life-expectancy-at-scotland-level.html)
- Northern Ireland Statistics and Research Agency. Latest data available at: [www.nisra.gov.uk/demography/default.asp130.htm](http://www.nisra.gov.uk/demography/default.asp130.htm)