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Demography and public health

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Introduction to demography and public health

The health and healthcare needs of a population cannot be measured or met without knowledge of its size and characteristics. Demography is concerned with this and with understanding population dynamics—how populations change in response to the interplay between fertility, mortality, and migration. This understanding is a prerequisite for making the forecasts about future population size and structure which should underpin healthcare planning. Such analyses necessitate a review of the past. The number of very old people in a population, for example, depends on the number of births eight or nine decades earlier and risks of death at successive ages throughout the intervening period. The *proportion* of very old people depends partly on this numerator but more importantly on the denominator, the size of the population as a whole. The number of births in a population depends on current patterns of family building, and also on the number of women 'at risk' of reproduction—itself a function of past trends in fertility and mortality. Similarly, the number and causes of deaths are strongly influenced by age structure.

Demography is largely concerned with answering questions about *how* populations change and their measurement. The broader field of population studies embraces questions of *why* these changes occur, and with what consequences.

This chapter presents information on demographic methods and data sources and their application to health and population issues, together with information on demographic trends and their implications and the major theories about demographic change, in order to elucidate the complex interrelationship between population change and human health.

Global issues

Fig. **6.3.1** shows that the world's population has recently been growing at an unprecedented rate and was estimated to be 7.05 billion at mid 2012 (UN 2011). While it took an estimated 123 years (from 1804 to 1927) for the world to increase its population from 1 to 2 billion, the increase from 6 to 7 billion was achieved in a tenth of the time (1999–2011). The United Nation's (UN's) medium projection suggests a further increase of some 2.3 billion by 2050 (UN 2011). Beyond this, there is a good chance that global population growth will cease by the end of the twenty-first century (Lutz and Samir 2010).

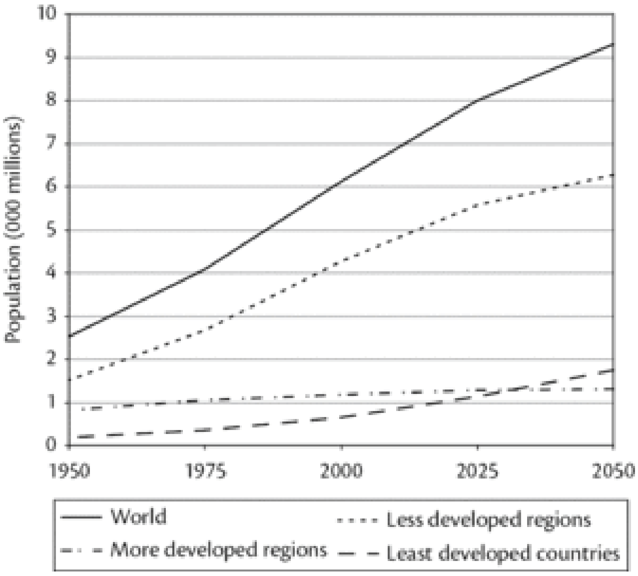

Fig. 6.3.1
Population and projected population of the world and more, less, and least developed regions, 1950–2050.

Source: data from United Nations, *World Population Prospects: The 2010 Revision,* United Nations, New York, USA, Copyright © 2011, available from http://esa.un.org/unpd/wpp/Excel-Data/population.htm.

This prospect of global population stability masks huge differences between regions and between richer and poorer countries. Between 1950 and 2000, 77 per cent of world population growth occurred in countries currently designated by the UN as less developed (excluding the least developed, see Box 6.3.1 for definitions); 13 per cent in least developed countries and 11 per cent in more developed regions. Between 2000 and 2050, medium-term projections suggest that population growth in more developed regions will account for only 4 per cent of the total with 63 per cent occurring in less developed countries and 33 per cent in the least developed countries. These projections imply that by 2050 the share of the world's population living in currently more developed regions will account for only 14 per cent of the total world population—compared with 32 per cent a century earlier—while the representation of those in the poorest countries will have increased from 8 per cent of the total in 1950 to 19 per cent in 2050.

Box 6.3.1 Country and regional classifications by level of development

The UN classifies countries into 'more' and 'less' developed and also identifies a group of 50 'least developed' countries. The more developed category includes all of Europe, North America, Australia, New Zealand, and Japan. The least developed countries are mostly in sub-Saharan Africa but also include Afghanistan, Bangladesh, Cambodia, and Myanmar. The classification has some anomalies in that some wealthy Asian and Near Eastern countries are counted as less developed (e.g. South Korea, Singapore, Cyprus, Israel) whereas some poorer former Eastern bloc countries are treated as more developed (e.g. Albania, Belarus, Bulgaria).

The World Bank employs a classification based on gross national income per capita which divides countries into high-, middle-, and low-income groups, with a subdivision of the middle into upper and lower. Some of the countries (principally from Eastern Europe) classified by the UN as developed fall into middle-income categories, while some of the UN less developed group are classified by the World Bank as middle income (principally Latin American) or high income (some South East Asian).

Membership of the Organisation for Economic Cooperation and Development (OECD) is also sometimes used as an indicator of developed country status; members include Russia and Mexico, both of which are classified by the World Bank as middle- rather than high-income countries.

The Human Development Index compiled by the UN Development Programme takes into account factors other than income, such as school enrolment, literacy, and levels of mortality.

Regional groupings employed by different international agencies also vary slightly. Further details of all these classifications are available on the relevant organizations' websites.

While some regions grapple with the needs of rapidly growing populations, such as large increases in requirements for child health services and schools, others face challenges of population ageing and, in some cases, population decline. By 2025, nearly a quarter of the Western European population is expected to be aged 65 or more and in some countries, such as Japan, South Korea, Spain, and Italy, projections suggest that a third or more of the population will be aged 65 and over by 2050 (UN 2011).

These hugely differing rates of growth arise from differences in vital rates, and associated large variations in age structures, which are illustrated for regions and selected countries within them in Table 6.3.1. In a number of European countries and some Asian countries, such as Japan, women on average have only 1.4 children or fewer (see Box 6.3.2 for derivation of total fertility rate), and people aged 65 and over outnumber children under 15. In sub-Saharan Africa, women on average have five children each, 40 per cent or more of the population is aged 15 or under, and only 3 per cent aged 65 or more.

Table 6.3.1 Indicators of age structure, fertility, and mortality: world regions and selected countries, 2011

Region/country		**Proportion (%) of population aged:**		**Total fertility rate**	**Life expectancy at birth (years)**
		<15	**65 and over**		
Africa		41	3	4.6	58
	Sub-Saharan	43	3	5.0	56
	Northern	33	5	3.1	70
Asia		25	7	2.2	70
	India	30	5	2.6	67
	China	18	9	1.5	75
	Japan	14	23	1.4	84
	Indonesia	27	6	2.3	71
	South Korea	16	11	1.2	79
Australia		18	14	1.8	82
Europe		15	16	1.6	76
	Italy	14	20	1.4	82
	Poland	15	14	1.3	76

	Germany	13	21	1.4	80
	Sweden	15	20	1.7	81
	Ukraine	14	15	1.3	69
	UK	17	16	1.9	80
Latin America and Caribbean		27	7	2.2	74
	Brazil	25	7	1.8	73
	Chile	22	9	1.9	78
	Guatemala	38	4	3.3	71
North America		19	14	2.0	79
	United States	20	13	2.1	78
World		26	8	2.4	68

Source: data from United States Census Bureau, Population Division, International Programs Center, International Data Base, available from http://www.census.gov/population/international/data/idb/informationGateway.php.

Levels of mortality, and associated differences in age and cause distribution of death, also vary markedly. In some high-income countries, average life expectancy at birth is above 80, while in some sub-Saharan countries it is below 50, substantially because of HIV/AIDS. As shown in Fig. **6.3.2**, in Sierra Leone, 40 per cent of all deaths in a year are of infants and children aged under 5, compared with 0.3 per cent in Japan. Conversely, of all deaths, 70 per cent in Japan and 50 per cent in Chile, a middle-income country, are of people aged 75 and over; equivalent proportions for Egypt and Sierra Leone are 20 per cent and 8 per cent respectively. These variations have enormous implications for health and healthcare priorities in, and beyond, the populations concerned. Divergence in population growth between regions of the world is also fuelling mass migration, which itself has implications for global population health (Fernandes et al. 2007).

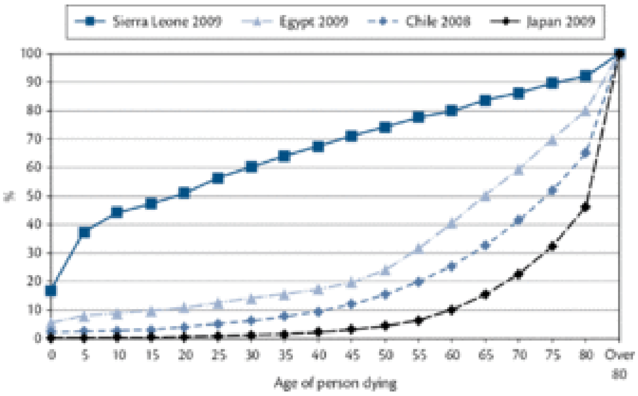

Fig. 6.3.2
Cumulative distribution of deaths by age; Sierra Leone 2009, Egypt 2009, Chile 2008, Japan 2009.

Source: data from United Nations Department of Economic and Social Affairs, Demographic Yearbook 2011, ST/ESA/STAT/SER.R/41, United Nations, New York, USA, Copyright © United Nations 2012, available from http://unstats.un.org/unsd/demographic/products/dyb/dybsets/2011.pdf

Closely related to variations in the distribution of deaths by age are differences in the cause structure of death. As shown in Table 6.3.2, communicable diseases, maternal and perinatal conditions, and nutritional deficiencies account for 67 per cent of all deaths in sub-Saharan Africa but only 5 per cent in Europe. Conversely, non-communicable diseases are responsible for 25 per cent of deaths in sub-Saharan Africa, 66 per cent in Asia, but 88 per cent in Europe. While in parts of the world, communicable diseases and reproductive and child health present the most pressing public health problems, concerns about the prevalence of age-related chronic degenerative diseases predominate in others. In sub-Saharan Africa, 1.2 million deaths are due to HIV/AIDS. Although the numbers of such deaths are estimated to have peaked globally around 2005 (UNAIDS 2012), they still represent a substantial and long-term burden (UN 2011).

Table 6.3.2 Distribution of deaths (%) by cause group and world region, 2010

	Communicable	**Non-communicable**	**Injuries**
Global	24.9	65.5	9.6
Europe	5.1	88.3	6.6
North America	5.3	88.0	6.8
High-income Asia and Pacific	11.4	81.1	7.5
Oceania	15.1	78.1	6.9
Latin America and Caribbean	14.2	69.0	16.8
North Africa and Middle East	16.2	75.2	8.6
Asia (excl. high-income and Middle East)	23.3	66.2	10.4
sub-Saharan Africa	66.5	24.9	8.6

Source: data from Global Burden of Disease Study 2010, Mortality Results 1970–2010, Institute for Health Metrics and Evaluation (IHME), Seattle, Washington, USA, Copyright © 2012, available from http://ghdx.healthdata.org/record/global-burden-disease-study-2010-gbd-2010-mortality-results-1970-2010.

The process that separates populations with high fertility, relatively high mortality, young age structures, and rapid growth from those with low vital rates, older age structures, and slow or no growth, is conceptualized as the demographic transition. Identifying, and explaining, this and associated profound changes in health has been a central preoccupation of modern demography (Lee 2003). Before turning to these issues, the basic methods and materials of demographic analysis must be considered and the issue of population dynamics—*how* populations change—addressed.

Demographic data and methods of analysis

In the seventeenth century, John Graunt, a London merchant, used data from the London Bills of Mortality to devise an early life table, leading to him being dubbed the ‘father of modern demography’. However, while Graunt had information on *numbers* of deaths, he lacked data on the population at risk and could not compute death *rates*. Essentially all demographic analysis requires data both on the population ‘stock’ and on ‘flows’ in and out—births, deaths, and migration. The traditional sources of information on the former are population censuses and, for the latter, vital registration systems.

Population censuses

The first 'modern' censuses were undertaken in Scandinavia in the eighteenth century. Censuses spread throughout Europe during the nineteenth century and most of the rest of the world in the twentieth. As well as basic questions about age, sex, marital status, and place of residence, data on other characteristics such as employment, education and housing are often collected. The UN recommends that censuses be conducted at least decennially in years ending in 0 or 1.

Censuses have many strengths and are often the only source of data for small areas or population subgroups. Although primarily a tool for collecting data on population 'stock', censuses have also been used to find out about vital events. Many countries use censuses to provide data on recent internal migration (through questions on place of residence 1 or more years earlier) and immigration (through questions on country of birth and/or date of entry for those born elsewhere). Indirect estimation techniques developed by Brass and others mean that questions on number of children born and number who have died, on widowhood, and orphanhood are widely used to assess mortality levels and trends using both censuses and surveys in countries with deficient vital registration systems (Preston et al. 2001).

However, censuses involve huge costs and the challenge of ensuring acceptable data quality. Approaches to reducing cost (and improving quality) include use of sample censuses, either for the census as a whole, as in China, or for more detailed questions, as in the United States. Census taking requires not only a reasonable administrative infrastructure, but also the cooperation of the population to be enumerated. Some countries have given up taking censuses because the latter is lacking and now rely on large-scale surveys or 'virtual censuses' based on population registration data. The twenty-first century is seeing more countries adopting alternatives as the information required by governments becomes more complex and the difficulties of mass data collection escalate. In 2010, only 11 of the 27 current European Union members conducted traditional censuses (Valente 2010).

When censuses are taken, difficulties arising from errors and omissions are common, even in countries with a long history of census taking. Young, geographically mobile adults, recent (especially unauthorized) immigrants, members of minority ethnic groups, infants, and the very old are those most likely to be under-enumerated—some of the very groups that policymakers and health professionals may be most keen to know about.

Groups such as seasonal migrants, military personnel, people temporarily away from home, and those with more than one residence also present problems. Not only are they more likely to be missed, but a decision has to be made about whether they should be assigned to their place of usual or legal residence (assuming it can be determined), or counted as belonging to the place of enumeration. The former system is termed *de jure*, the latter *de facto*. The issue of assigning people to some place of usual residence is important as often resources are allocated based on population size and characteristics. Moreover, it is essential to try and ensure that demographic events recorded in one system (vital registration) are attributed to the population actually 'at risk' of experiencing them. In richer countries, for example, most deaths occur in hospitals which may draw patients from a wide area. If these decedents are not assigned to the locality where they lived prior to hospital admission, areas including large hospitals will appear to have very high mortality rates while in others, recorded mortality will be artificially low.

Under-enumeration is usually assessed through census validation surveys (surveys of a sample of census addresses in which intensive efforts are made to contact non-respondents and check information supplied by respondents) and comparisons with population estimates from other sources. Beyond ensuring near-complete enumeration, the quality of the data collected is also a major concern.

In many populations, people may not always know their exact age and some approximation is reported or made by an enumerator. ‘Heaping’ on ages ending in 0 or 5 is a common result. Heaping can be detected by looking at the age distribution and applying various tests of consistency and such data are normally adjusted before publication. More serious problems arise when reported age is based on other characteristics, such as marital status, number of children or grandparent status, as clearly any analysis of, for example, age at first marriage, will be biased if people’s report of their age is influenced by their marital status.

Vital registration

Data on demographic events, as well as on population characteristics, are needed. In richer countries these are drawn from vital registration. Compulsory registration of births and deaths was established in most European countries during the nineteenth century. In England and Wales, for example, civil registration was introduced in 1837. Subsequent improvements to the system included those following the 1874 *Births and Deaths Registration Act* which made parents legally responsible for registering births and required attending physicians to supply information on cause of death. Other revisions have since been made, for example, the inclusion of first mother’s and later father’s age and in 2012, recording of all children previously born, rather than just legitimate ones, on the confidential section of birth certificates. Most high-income countries have well-established registration systems with complete, or very near complete, coverage. In poorer parts of the world, however, vital registration systems are frequently seriously incomplete or non-existent, although there are exceptions and some countries, including India and China, have sample registration systems for selected areas. Currently only about a third of deaths estimated to occur globally are registered and reported to the World Health Organization, although if the sample registration systems in India and China are considered as sufficiently representative of their national populations, this proportion rises to 72 per cent (Mathers et al. 2005).

The quality of the information supplied and coded is of course very important. No one registers their own death and the information obtained from proxy informants may be inaccurate. Differential reporting of age, occupation, marital status, or other characteristics in the census and in other sources, such as death certificates, presents a further difficulty. Numerator–denominator discrepancies may introduce serious bias into the analysis of mortality at advanced ages, or by characteristics such as occupationally defined social class, marital status, or ethnicity (Williams et al. 2006). The Nordic and some other European countries avoid these problems by maintaining well-developed register-based systems that link vital registration data to population, occupational, and educational registers. One study of marital status differences in mortality at older ages found marked differences in results for countries using traditional and register-based systems (Murphy et al. 2007).

Cause of death

Death certificates are the major source of information on cause of death. In richer countries, cause of death is generally certified by a physician and coded according to the International Classification of Diseases (ICD) which originated from work undertaken by the nineteenth-century British medical statistician, William Farr. The tenth revision of the ICD came into use from 1994 and included nearly twice as many codes as ICD-9. ICD-11 is in preparation and is expected to come into use in 2015. National preferences, as well as ICD revisions, may influence assignment of cause of death, as illustrated in a number of classic papers in which case studies of deaths were distributed to physicians in different countries. Growing awareness of particular conditions may also influence coding practices. In the United States, Australia, and elsewhere, for example, there have been large increases in mentions of Alzheimer's disease and other dementias on death certificates since 2000. These partly reflect some changes associated with the introduction of ICD-10 but also effects of increased awareness and some specific campaigns to increase recognition of these conditions (Moschetti et al. 2012).

Older people, now the vast majority of decedents in low-mortality populations, are more likely to suffer multiple pathologies and the number of conditions recorded on death certificates has been increasing. Choice of one over another as the 'true' underlying cause of death is bound to be partially arbitrary. In the United Kingdom, for example, between 1984 and 1992 some 25 per cent fewer deaths were allocated to respiratory diseases purely as a result of changes in the rules used to select underlying cause of death (Griffiths and Brock 2003). Multiple coding of death certificates and analyses by all mentions of a condition may be more informative but such data are available in only a few countries (Anderson 2011). Variations in death certificate coding reflecting differences in medical knowledge and diagnosis, in the extent to which autopsies are used, in classification systems, and the quality of registration systems are a major factor complicating analyses of trends over time or between countries.

Deaths assigned to symptoms, signs and ill-defined conditions such as 'old age' or 'senility' or other causes lacking diagnostic meaning, sometimes referred to as 'garbage codes', present a particular problem. Mathers et al. (2005) in an investigation of coverage and quality of cause of death coding in 2003, found that in some countries over 40 per cent of deaths were assigned to these 'causes'. Only 23 countries met their definition of high quality of data with coverage of at least 90 per cent and fewer than 10 per cent of deaths assigned to ill-defined codes.

Variations in coding practices and use of ill-defined codes complicate comparisons over time, as well as between countries. Preston (1976) argued that there was an inverse association between the proportions of deaths assigned to circulatory diseases and to ill-defined causes, and that part of the apparent twentieth-century epidemic in heart disease mortality in richer countries may have been an artefactual consequence of improvements in death certification. A review of the proportion of all deaths in England and Wales assigned to circulatory diseases and to ill-defined causes in age groups over 65 from 1911–1915 to 2001–2010 is instructive. Early in the twentieth century, large proportions of deaths among the very old were assigned to ill-defined categories and declines in this proportion were associated with increases in the proportion attributed to circulatory diseases. The proportion of ill-defined deaths in the oldest group aged 80 and over was, however, slightly higher in 2001–2010 than in the preceding period, reflecting increased assignment to 'old age' as a cause. Reasons for this are unclear, although the cessation in 1993 of further enquiry into vague causes of death may have been a small contributory factor. Use of this 'cause of death' is likely to be reversed again in response to the 2000–2005 public enquiry into the case of Harold Shipman, a British family doctor whose serial murder of over 250 elderly patients was not detected for many years; an illustration of the importance of surveillance of deaths for reasons other than epidemiological or demographic investigation.

In countries which lack adequate certification and registration systems, data on deaths by cause are seriously limited. Attempts have been made to develop verbal autopsies, protocols for collecting information from lay informants which can be reviewed by physicians and used to assign cause of death (Wang et al. 2007). This approach has been useful in a number of small investigations and is being employed on a larger scale, for example, in India (Gajalakshmi and Peto 2011). However, a recent study tested physician-certified verbal autopsies in six sites in four poorer countries against gold standard assessment and found a concordance of less than 50 per cent, with substantial variability by cause and physician (Lozano et al. 2011). In the absence of routinely recorded data, estimates may be obtained by modelling. This has been used for the important issue of establishing the number of deaths from HIV/AIDS. The most ambitious exercise is the Global Burden of Disease programme which has used a large array of sources and methods, including expert knowledge, vital registration, field surveys, surveillance, and police and mortuary data to derive estimates of cause-specific mortality by age and sex for 235 separate causes for every country in the World (Wang et al. 2012).

Other data sources

Many countries have a range of surveys which provide more detailed information on, for example, health-related behaviour, family building strategies, reasons for migration, or information on biomarkers that would be impossible to collect in a census. In poorer countries, where other data sources are scarcer, surveys often present the best source of data on basic demographic parameters. Data quality is potentially better in a survey than a census, as it is more likely that well-trained interviewers can be used. The World Fertility Survey (WFS), an international population research programme launched in 1972 to determine fertility levels throughout the world, and its successor, the Demographic and Health Survey Programme (DHS), have been particularly valuable in providing demographic and health data for a range of poorer countries. Other approaches include multi-round surveys, in which respondents are asked about events since last contact, and dual-record systems which involve two independent data collection systems (one often a multi-round survey), the results of which are then combined. This method allows some estimation of missed events, but is expensive. These approaches are described in more detail in most demographic textbooks (Preston et al. 2001; Rowland 2003; Siegel and Swanson 2004).

The raw materials of demography relate to individuals’ most personal experiences—sexual activity, family formation, birth control, reproduction, marital breakdown, illness, and death. All of these occur in a social framework which attaches value to some of these behaviours and stigmatizes others. Not surprisingly, respondents in censuses and surveys may be reluctant to disclose non-marital pregnancies, illegal abortions, undocumented migration, or deaths of relatives from AIDS. Concealment has also been the policy of some national governments which have treated demographic data as official secrets. Additionally, the enormous potential complications arising from people’s uncertainties about age or other ‘basic’ characteristics including children ever-born; uncertain recollections of prior events and the vast scope for administrative errors have to be considered. The demographer’s traditional obsession with data quality is hence understandable. Differences in perceptions and reporting of health status are also problematic and have bedevilled attempts to make international comparisons of health status as, even if questions are harmonized, the ways people respond to them are not (Ritu et al. 2002).

The statistics produced in series like the *United Nations Demographic Yearbooks* have their origins in what is or has been *done* by millions of people, mediated by what is *said* about these events and experiences, further filtered by how this is *recorded*, processed and analysed. Some assessment of data quality is given in the *United Nations Demographic Yearbooks*, but sometimes users may pay insufficient attention to this. A number of other organizations also produce international reference works and databases including the World Health Organization (WHO), the World Bank, the Organisation for Economic Cooperation and Development (OECD), Eurostat, The United States Census Bureau International Data Base (United States Census Bureau n.d.), and the Human Mortality Database. In most cases, these are available free of charge online.

The analysis of demographic data

A standard array of techniques and measures forms the basis of much demographic analysis; the most common of these are described briefly here. Further detail is supplied in a number of textbooks (Preston et al. 2001; Rowland 2003; Siegel and Swanson 2004). Analysis involves not just the application of a particular technique, but also decisions about what units of analysis to use and how to group them. A major distinction is between *period* and *cohort* analysis. Period analysis deals with events of a particular time period (e.g. mortality rates from 2005 to 2010) while cohort analyses follow the experience of individuals through time. Cohorts in this sense are defined as groups of people who have experienced the same significant event at the same time. Thus birth cohorts comprise people born in a particular year or group of years and marriage cohorts those marrying at a particular time. Cohort and life-course approaches to analysing mortality and other indicators of population health have an intuitive appeal and are increasingly used, both fuelling and fuelled by a growing number of longitudinal studies. Cohort analysis of time series data may be used in the absence of specially collected longitudinal data.

Cohort and period are two of the dimensions which ‘place’ persons in time; the third is age. Duration effects (such as duration of marriage, proximity to death, or length of exposure to a particular pathogen) may also be important. Cohort effects may be substantial and, unless allowed for, may mask relationships between age and various risks. Differences in the smoking behaviour of cohorts, for example, have a major effect on the relationships between age and smoking-related disease observed at different periods (Grundy 1997).

Decisions about whether to use individuals, families, households, or geographic areas as units of analysis are often constrained by data availability. Until relatively recently, most census data were only available as aggregate tabulations, but individual-level information is increasingly available. Other innovations include the development of samples including linked census, vital registration, and in some cases health service data such as the Longitudinal Studies available for countries of the United Kingdom and a number of others (Young et al. 2010). In these data sets, individuals’ census records are linked with their vital registration records so numerator–denominator biases in, for example, the analysis of mortality are avoided. In Nordic countries, the whole population has been assigned personal identification numbers facilitating linkage of information from a range of registers. Linkage to use of health and care services is also available in some countries, such as Finland.

These advances have greatly extended the material available for analyses of variations in demographic behaviour, and their consequences. They have also raised complex security and confidentiality issues fuelling debate over appropriate restrictions on access to data.

The measurement of fertility

Fertility means the childbearing performance of a woman, couple, or population. Generally only live births are included. The term fecundity, by contrast, is used to refer to the physiological capability of producing a live-born child. A rough idea of fertility may be gained from using census or survey data to calculate child–woman ratios: the ratio of 0–4-year-olds to women aged 15–49. However, the survival of infants (and their mothers) and the age structure of the female population affects these ratios, so they are generally only used if no other data are available.

The simplest measure of fertility commonly used is the crude birth rate—the number of births in a particular year per 1000 population. As the denominator of this includes those not 'at risk' of giving birth (women outside reproductive age groups and men), it is really a ratio rather than a rate. Crude birth rates are influenced by the age structure of the population, but less seriously so than crude death rates. In 2005–2010 crude birth rates ranged from less than 10 per 1000 in parts of Europe to nearly 50 per 1000 in the highest fertility countries of sub-Saharan Africa.

Slightly more sophisticated is the general fertility ratio—births per 1000 women of reproductive age (generally defined as aged 15–49 or 15–44). Where data allow, age-specific fertility rates (births per 1000 women of a particular age or age group) are preferred. These are frequently summarized using the total fertility rate (TFR). Where, as is usually the case, period data are used to calculate this, it indicates how many children women in a hypothetical cohort would have if they experienced current age-specific fertility rates throughout their reproductive life. This measure is sometimes explicitly denoted TPFR (total period fertility rate). In low-mortality populations, a TFR of 2.1 is taken to indicate *replacement level* fertility as, under this regime, a cohort of women would be succeeded by a cohort of daughters of the same size (after some allowance for mortality and the fact that 105–106 boys are born for every 100 girls).

One difficulty with the TFR is that it is affected by changes in the 'tempo' as well as the 'quantum' of childbearing. If women start delaying their fertility but 'catch up' later, there will be a divergence between cohort and period measures, as the latter will be based partly on the behaviour of earlier cohorts whose timing of births was different. Similarly, if women have children earlier, TFRs will rise, even if eventual family sizes remain unchanged. This means that period measures are much more volatile than cohort ones. For example, the US TFR, having risen in the early parts of this century, fell by more than 10 per cent, from 2.12 to 1.89, between 2007 and 2011 (Hamilton et al. 2012). For these reasons, many statistical offices use cohort, rather than period, measures of fertility as the basis for projections.

More sophisticated measures of fertility include parity progression ratios. These indicate the probability of proceeding from one birth to another (e.g. what proportion of mothers with two children progress to having a third). Parity progression ratios are normally calculated for cohorts who have completed, or nearly completed, their childbearing but it is also possible to use data on births by birth order to derive period progression ratios (Bongaarts and Feeney 1998).

In the past, demographers often preferred to calculate age-specific *marital* fertility rates (and TFRs and other measures) on the grounds that the unmarried population is not 'at risk' (or at reduced risk) of childbearing. Changes in marital fertility indicative of deliberate attempts to limit family size are regarded as one of the defining features of the fertility 'transition' (see later) and so distinguishing these from changes due to variations in the 'at risk' (married population) has been particularly emphasized. However, rises in non-marital childbearing, which now account for over 40 per cent of births in countries such as France, the United States, and United Kingdom, mean that restricting analyses to marital fertility is generally no longer appropriate.

Reproduction rates

In the absence of migration and with fixed mortality, populations will grow if mothers replace themselves with more than one (surviving) daughter and decline if they have fewer than one. Theoretically, it would also be possible to measure the replacement of fathers by sons, but in practice the difficulties involved in obtaining paternity data make this infeasible. Reproduction rates thus relate only to female fertility—births of daughters. The gross reproduction rate (GRR) is derived in the same way as the TFR except that age-specific birth rates based only on births of daughters are used in the calculation. The net reproduction rate (NRR) makes an allowance for mortality; specifically the chance that a daughter will herself survive to childbearing age. The NRR cannot be calculated unless both age-specific fertility and mortality data are available (although it can be approximated using the GRR and appropriate life table survival data). Changes in either fertility or mortality (or both) will mean a divergence between period measures (based on the experience of a hypothetical cohort) and the experiences of real cohorts.

Summary information on measures of fertility and reproduction is shown in Boxes 6.3.2 and 6.3.3.

Box 6.3.2 Fertility measures

Definitions

Fertility: the childbearing performance of individuals, couples, or populations.
Fecundity: the physiological capability of producing a live birth.
Parity: the number of children previously born alive (or sometimes number of previous confinements) to a woman or couple. Nulliparous women are those who have borne no children.

Measure

Crude birth rate: the ratio of births in a year (other specified period) to the average population in the same year/period (mid-year population), expressed per 1000:

$$\mathrm{CBR} = \frac{\text{number of births}}{\text{mid-year population}} \times 1000.$$

General fertility rate: births to women aged 15–44/49 in a year/period per 1000 women aged 15–44/49 in the same period:

$$\mathrm{GFR} = \frac{\text{number of births to women aged } 15-44/49}{\text{mid-year population of women aged } 15-44/49} \times 1000.$$

Age-specific fertility rate (ASFR): number of births to women aged x (or x to x + n) per 1000 women aged x (or x to x + n). 'n' refers to the length of an age interval.

ASFRs are frequently calculated for 5-year age groups from 15–19 to 40–44 or 45–49.

$$\mathrm{ASFR} = \frac{\text{births to women aged x}}{\text{mid-year population of women aged x}} \times 1000.$$

Total (period) fertility rate (TFR/TPFR): the sum of the age-specific fertility rates for all reproductive age groups for a particular period (usually a year), conventionally expressed per woman. The TFR indicates how many children a woman would have if throughout her reproductive life, she had children at the age-specific rates prevalent in the specified year or period.

x = 49:

$$\mathrm{TFR} = \sum_{x=15}^{x=49} f_x$$

where 'f_x' is the age-specific fertility rate at age x. If rates for age groups, rather than single years, are used then the sum of the age-specific rates must be multiplied by the number of single ages included in the group (usually five).

x = 45–49:

$$\mathrm{TFR} = 5 * \sum_{x=15-19}^{x=45-49} f_x.$$

Parity progression ratio: the probability of a women of parity x progressing to parity x + 1.

Box 6.3.3 Reproduction rates

Measures

Gross reproduction rate (GRR): the sum of the age-specific female fertility rates (births of daughters), for all reproductive age groups for a particular period (usually a year) conventionally expressed per woman. The GRR indicates how many *daughters* a woman would have if, throughout her reproductive life, she had children at the age-specific rates prevalent in the specified year of period. The GRR can be calculated either by summing female age-specific fertility rates (relating to births of daughters rather than all births) or using the formula:

$$\mathrm{GRR} = \mathrm{TFR} \times \text{proportion of female births.}$$

The proportion of female births can be taken as 0.488 (100/205) in the absence of more detailed information.

Net reproduction rate (NRR): the average number of daughters that would be borne, according to specified rates of mortality and of bearing daughters, by a female subject through life to these rates. The NRR employs the same fertility data as the GRR, but also takes into account the effects of mortality. An NRR of 1.0 indicates that a population's fertility and mortality levels would result in exact replacement of mothers by daughters.

The measurement of mortality

As for fertility, the simplest measure of mortality is the crude mortality rate, deaths per 1000 population. This is strongly influenced by age structure. Although life expectancy at birth in the more developed regions of the world in 2005–2010 was some 10 years longer than in less developed regions (76 years and 66 years respectively), crude death rates—deaths per 1000 population of all ages—were higher in the more developed regions (10.0 compared with 8.0 in less developed regions) (UN 2011). Age (and sex) specific rates, or measures based on them, are therefore much to be preferred if data are available to calculate them. Both direct and indirect standardization are sometimes used to make comparisons between populations with different age and sex structures. Standardized mortality ratios (SMRs) are calculated using indirect standardization. This involves selecting a set of 'standard' age-specific mortality rates, for example, those for a national population, and applying these to the numbers of people in the relevant age groups in the subpopulation of interest—for example, the population of a particular region. This yields an 'expected' number of deaths—the number of deaths there would be in the subpopulation if age-specific death rates were the same as those in the standard population. The ratio of observed to expected deaths gives the SMR. Thus an SMR of 1.24 indicates that mortality in the sub population is 24 per cent higher than in the standard population, after allowing for age differences. SMRs are useful summary measures of differences in mortality, but give no indication of the *level* of mortality. In direct standardization, widely used by WHO and national statistical offices, age and sex specific rates are applied to an external 'standard' population, such as the European Standard Population, to produce an overall standardized (weighted) death rate.

Age-specific death rates are calculated using the numbers of deaths at age x (or between ages x and x + n) in a particular year as the numerator and the mid-year population of the same age as the denominator. The rate is conventionally expressed per 1000 or per 100,000 population. The mid-year population is used as a measure of the average population at risk on the assumption that deaths are evenly distributed throughout the year. For some age groups, notably infants, this assumption is invalid. In low-mortality populations, deaths in the first 3 days of life may account for half or more of all deaths in the first year of life. Moreover, information on the size of population aged less than 1 normally comes from birth data (as in 9 out of 10 years relevant census data will not be available). For these reasons live births in a particular year are conventionally used as the denominator of the infant mortality rate while deaths to infants aged less than 1 constitute the numerator. Some infants dying in a given year will have been born in the previous year and some born in the year in question will die the following year. This can cause distortions if there are large annual fluctuations in numbers of births (or infant deaths) and often 3-year averages are preferred. Deaths at very old ages are also not evenly distributed throughout the year and an adjustment is often made to allow for this.

Infant mortality rates (IMRs) were very high in some parts of historical Europe—with 300 or even 400 deaths per 1000 live births in regions of Russia and Germany at the end of the nineteenth century (van de Walle 1986). In England and Wales at the start of the twentieth century, there were some 140 infant deaths per 1000 live births. Infant mortality in high-income countries is now extremely low—fewer than five infant deaths per 1000 live births in many European countries, Australia, Japan, South Korea, Hong Kong, and Singapore. There have also been huge falls in infant mortality in many poorer countries; in 2011 China and India had reported IMRs of 13 and 47 respectively (WHO 2013). Rates remain high in some of the very poorest countries—over 100 deaths per 1000 live births.

Variations on this scale have substantial demographic impacts. Infant mortality has also attracted particular interest because of links with fertility behaviour and as an indicator of public health conditions. Particularly in this latter context, perinatal, early and late neonatal and post neonatal mortality rates are often distinguished where data allow (see Box 6.3.4).

Box 6.3.4 Mortality measures

Measures

Crude death rate: the ratio of deaths in a year (other specified period) to average population in the same year/period (mid-year population), expressed per 1000:

$$\mathrm{CBR} = \frac{\text{number of deaths}}{\text{mid-year population}} \times 1000.$$

Age-specific mortality rate (ASMR): number of deaths to persons aged x (or x to x + n) per 1000 persons aged x (or to x + n):

$$\mathrm{ASMR} = \frac{\text{deaths to persons aged x}}{\text{mid-year population of persons aged x}} \times 1000.$$

Standardized mortality ratio (SMR): the ratio of observed to expected deaths in a study population. Expected deaths are calculated by applying a set of standard age-specific mortality rates to the age distribution of the study population. Standardized ratios are only useful for comparisons. They have no intrinsic meaning.

Infant mortality rate (IMR):

$$\frac{\text{number of deaths to infants ages} < 1 \text{ year}}{\text{number of live births}} \times 1000.$$

Sometimes decomposed into *neonatal mortality rates* (deaths of live born infants during the first 4 weeks) and *post-neonatal* mortality (from 4 to 52 weeks).

The *perinatal mortality rate* measures late fetal deaths (stillbirths) and early neonatal deaths relative to live births.

$$\text{Perinatal mortality rate} = \frac{\text{stillbirths} + \text{deaths under 1 week}}{\text{still+live births}} \times 1000.$$

Stillbirths used to refer to deaths of fetuses of 28 or more weeks' gestation; however, an earlier threshold of 24 weeks is now more generally used.

Life tables

Life table analysis is a core demographic technique and life tables provide one of the most powerful tools for analysing mortality and other demographic processes. Life tables show the probability of dying (and surviving) between specified ages. They also allow the calculation of various other indicators, including expectation of life. If complete data on the mortality of a birth cohort are available, then a cohort life table may be constructed. However, the use of cohort life tables is obviously only possible retrospectively. More commonly, period life tables, based on mortality rates at a particular time, are calculated. These life tables show death (and survival) probabilities for a hypothetical cohort with an arbitrary radix (number of babies at the beginning) usually set to 10,000, 100,000 or some other multiple of 100.

Specific notation, summarized in Box 6.3.5, is used in life table analysis. The basis of the table is a set of probabilities of dying—${}_nq_x$—which are calculated from age-specific death rates; x here refers to age at the start of an interval whose length is specified by n. Thus ${}_5q_{50}$ refers to the probability of someone alive at 50 dying between age 50 and age 55. The complement of ${}_nq_x$—the probability of surviving—is denoted ${}_np_x$. The (hypothetical) number of survivors at each age is given by l_x; thus l_o equals the radix (of 100,000) and l_{75} the number of survivors at age 75. The number of person years lived in an interval (${}_nL_x$) and the total number of person years lived after a particular age (T_x) are often not shown in published tables but are steps on the way to the calculation of e_x—life expectancy at age x.

Box 6.3.5 Life table measures and notation

x = age attained last birthday.

l_0 = the radix of the life table (hypothetical number of babies), usually 100,000.

l_x = number of survivors at age x, so l_{65} is the number of persons alive at age 65 in the hypothetical life table population.

$_nq_x$ = probability of dying between age x and x + n, so $_4q_1$ is the probability of dying between age 1 and 5 for a person aged 1.

$_np_x$ = probability of surviving between ages x and x + n, so $_{20}p_{65}$ is the probability of surviving from age 65 to age 85 for a person aged 65.

$_nd_x$ = number of deaths between age x and x + n.

$_nL_x$ = number of person years lived between x and x + n.

T_x = total number of person years lived after age x.

e_x = expectation of life at age x, so e_0 is expectation of life at birth.

This measure provides an indicator of mortality which is very largely independent of the age structure of the population since it depends only on age-specific mortality rates. This makes it more useful than either a standardized mortality ratio (which gives no indication of level) or a crude death rate (which is strongly influenced by age structure). Life expectancy either at birth (e_0) or further life expectancy at a particular age, say 65 (e_{65}), is calculated by dividing the total person years lived after age 0 or 65 (T_0 or T_{65}) by the number of survivors aged 0 (l_0) or 65 (l_{65}).

Values of life expectancy at birth are sometimes (mis)interpreted as indicators of usual age at death in a particular population. In very low-mortality populations where most deaths occur within a relatively small range of ages (see the example of Japan in Fig. **6.3.2**); there will be a close correspondence between median and modal ages of death and life expectancy at birth (which is a mean value). However, in populations such as Sierra Leone where so many deaths occur in infancy, there will be a wide divergence. There is also sometimes confusion about the interpretation of values of further life expectancy at a particular age. This is derived from information about the probabilities of death and survival at *subsequent* ages, and so is not influenced by deaths at earlier ages and it is erroneous to think that, for example, the further life expectancy of someone aged 65 will equal life expectancy at birth minus 65. The higher the mortality rates at young ages the greater will be this divergence. In 2008, for life example, female life expectancy at birth in the United States was 80.6 years but the further life expectancy of women aged 65 was 20.0 years. The equivalent figures in 1900–1901 were 49 years and 12.0 years.

Model life tables

Patterns of age-specific death rates show similarities whatever the level of mortality. Death rates tend to be higher in infancy than later childhood and rise with age from around the age of puberty, although in the oldest age groups rates of increase tend to flatten out. Because of the tendency for death rates at one age to be associated with death rates at other ages in a given population, it is possible to derive hypothetical schedules, called *model life tables*, describing variations in mortality by age and sex, normally in terms of a limited number of parameters which allow for particular features of the mortality pattern of the population considered. Model life tables are derived from empirical data from countries where these are available. They are extremely useful aids for the estimation of mortality by age in populations with defective data.

They are also used (in conjunction with fertility data) to show the outcomes of particular fertility and mortality regimes on, for example, population age structure and for making population projections. All demographic texts give further details of their derivation and application.

Other applications of life table analysis

Life tables are widely used to analyse probabilities associated with events other than death, such as risks of divorce or contraceptive use failure and discontinuation rates, and in estimates of disability-free or healthy life expectancy. Many chronic conditions associated with ageing, such as musculoskeletal and sensory impairments, may have serious implications for health status but are not directly life-threatening. Life table methods are used to decompose total life expectancy into ‘healthy’ and ‘unhealthy’ or ‘disabled’ components. This can be done using cross-sectional data on morbidity prevalence in conjunction with mortality data, although this has some limitations. More sophisticated (and data demanding) multistate approaches which allow transitions both to and from disabled states have also been developed (Manton et al. 2006). Despite these technical advances, there is still controversy about *trends* in indicators of the health status of populations, including disability. To a large extent this debate arises from measurement problems and the difficulties involved in making comparisons between health indicators derived in different ways, a further reminder of the importance of data quality and measurement.

Multiple decrement life tables allow ‘decrements’ from more than one event—for example, different causes of death. Cause elimination life tables are also used to identify the ‘pure’ severity of a particular cause of death. Multistate models allow analysis of a range of transitions, particularly those where re-entries into a particular state, such as being married or living in a certain region, are possible. These more sophisticated applications of course require more detailed data.

The measurement of migration

In many countries migration is the predominant influence on the spatial distribution of the population. In Asia and Latin America recent rural-to-urban migration has resulted in the phenomenal growth of cities, often lacking the infrastructure to meet the needs of the expanding population for basic services such as sanitation and power. In 2010, 52 per cent of the world’s population lived in urban areas compared with 29 per cent in 1950 (UN 2012).

Measuring migration represents particular difficulties. The classical definition of internal migration is a permanent or semi-permanent move across an administrative boundary, which means that the extent of migration recorded depends partly on the size of administrative areas. For example, in a country divided into many small areas, a move over 5 kilometres will count as migration, which would not be the case for countries divided into larger ones. Hence, international comparison of internal migration rates is potentially misleading. Even the distinction between international and internal migration may be problematic if boundaries are contested or changing. The temporal dimension to migration presents further difficulties; what constitutes permanent or semi-permanent and how should groups such as seasonal migrants be treated?

The reason for defining migration as a move over a boundary is largely pragmatic. Often only moves of this kind are recorded; moreover this is the information required by local administrations. For research purposes, analyses of *all* moves (preferably with an indication of distance moved) may often be preferred. Some countries have registration systems in which changes of address are recorded. More commonly, censuses are used to find out about migration. Questions on usual address 1 or 5 years ago allow the proportion of *movers* in the population to be measured (except for those aged less than 1 or 5). These data also allow inflows *and* outflows between pairs of areas to be measured. *Moves*, as opposed to *movers*, are not directly measured as someone moving several times in the reference period cannot be distinguished from someone moving only once. Those leaving an address and later returning to it cannot be identified either. This means that the length of the reference period used is important; the proportion of movers in the 5 years preceding a census will *not* equal five times the proportion moving in 1 year before the same census.

In the absence of direct census data, estimates of migration can be made indirectly using the 'balancing equation' referred to in the following subsection. Differences in the size of a population at two points in time not accounted for by natural change (i.e. births minus deaths) must be due to migration (or data errors). If vital registration data are available, then both births and deaths can be taken into account. If they are lacking, then the survival of groups enumerated in the first of a pair of censuses must be estimated from a life table and the number of expected survivors compared with the number enumerated in the second census (obviously ageing must be allowed for, so the number of 20–29-year-olds in the first census will be compared with 30–39-year-olds 10 years later). These methods only allow estimation of *net* migration (balance between in-migration and out-migration). Their major weakness lies in the fact that the residual population balance assumed to be due to migration may in fact reflect differences in the quality of the two censuses considered or errors in the estimates of survival used.

Survey data are also used to measure migration and potentially provide illuminating information on the reasons for, and consequences of, migration. However, as migration over long distances is a relatively rare event, even large general population samples may yield relatively few migrants. A similar problem besets samples of international travellers, such as the UK International Passenger Survey, designed to estimate flows of international migrants through port or border surveys. Tourists and business travellers comprise the vast bulk of people entering or leaving so surveys are an inefficient way of identifying immigrants and emigrants. Unfortunately, other data are often lacking as legal and administrative record systems are frequently concerned with citizenship and right of abode rather than international migration per se (and virtually never with emigration). Estimates of the size of immigrant populations depend on whether the measure used is based on place of birth or on nationality—the size of the latter is influenced by policies on acquisition of citizenship.

Population dynamics

Any population comprises those who have made an entry and not yet exited. When whole populations of defined geographic areas are considered, the only means of entry are birth or immigration and the only means of exit death or emigration.

The most basic method of demographic analysis is the decomposition of overall population change ($P_t - P_0$) into its components (B, D, I, E):

$$P_t - P_0 = B - D + I - E$$

where P_t = population at an end of period; P_0 = population at the beginning of a period; and B, D, I, E represent respectively births, deaths, immigrations, and emigrations during the same period (B – D is referred to as natural increase and I − E as net migration). Population subgroups may be similarly defined in terms of entries and exits. In the absence of migration, entry to the population aged 75–84 is through ageing (passage from 74 to 75) exit is through further ageing (84 to 85) or death. This simple accounting equation is an important one, both methodologically and as a formal reminder of the need to consider *past* as well as current events.

Of the three demographic determinants of population size, structure, and growth, fertility has historically been of much greater importance than either mortality or migration. Every birth represents not just an addition to the current generation of children, but also potentially an exponentially increasing augmentation in the size of future generations. Death carries no such promise of future return. Births increase the population only at age zero, so making it younger, whereas deaths are spread across the whole age range and so have much less impact on age structure. The third determinant—migration—is generally not of significant magnitude to have a major impact on most national populations, although there are exceptions especially when natural increase is close to zero. Increased levels of immigration to many European countries since the 1990s have had quite an effect on population size and age structure; the population of Spain for example, increased by 10.2 per cent between 1999 and 2006 and over 90 per cent of this increase was due to migration (Sobotka 2008).

For social and biological reasons fertility, mortality, and migration have interactive effects. Decreases in mortality among those with reproductive potential, for example, influence not just the size of the age group affected at the time, but also the size of succeeding generations. Declines in male mortality, particularly in populations where large age differences between spouses are common and remarriage of widows is rare, will similarly tend to increase fertility by effectively increasing the proportion of women of reproductive age who are still married. Conversely, reductions in fertility clearly reduce the risk of maternal mortality and may have further positive effects on the survival of mothers, infants or both. Age at motherhood also influences rates of population growth. The average age of mothers at the birth of their daughters is termed the mean length of a generation and is generally around 29 years. A shorter interval will mean more rapid generational succession (and faster population growth).

Migration affects other demographic parameters because migrants differ from the general population. International migrants are generally young and in good health and often move from relatively high- to low-fertility populations. Consequently, immigrants may serve to (temporarily) ‘rejuvenate’ the host population and, at least initially, have higher fertility and lower mortality. In England and Wales, for example, 24 per cent of births in 2011 were to mothers themselves born outside the United Kingdom. Despite the disadvantages they often face, mortality of immigrant groups is often lower than that of host populations because of the differential selection of immigrants. The degree of selection tends to vary according to difficulties and distance to be overcome in making an international move. For all these reasons, the demographic characteristics of population subgroups largely comprising immigrants and their immediate descendants may vary substantially from those of the population as a whole.

Population projections

Population projections represent one of the most widely used outputs of demographic analysis. Strictly speaking, a projection simply represents the outcome of applying various assumptions about future fertility, mortality, and migration and so differs from a *forecast*, which implies prediction. However, projections are often treated as forecasts and the degree of uncertainty inherent in them is not always sufficiently recognized, although the production of probabilistic forecasts, as in the latest UN projections, makes this more explicit. The most common method of projection is the component method, based on the balancing equation ($P_t = P_0 + B - D + I - E$). Assumptions are made about the three components of change—births, deaths, and migration—and applied to age and sex groups within the initial population to give a projection of future size and structure. To a large extent assumptions are based on recent trends together with other information, for example, survey data on fertility intentions or (sometimes) models of change in particular causes of death. Forecasting fertility has generally been regarded as the most problematic area of projection but recently greater attention has been paid to the errors that have been made in forecasting mortality in developed countries. This has little effect on age groups in which survival is high, but can have quite substantial impacts on forecasts of the number of older people. Migration may be an important element and may be underestimated, if projections do not take into account feedback loops whereby migrant populations tend to generate further migration (Bongaarts and Bulatao 2000). International migration is also difficult to forecast as it is affected by events outside the country, is often a sensitive political issue and may be volatile. Partly for these reasons, immigration levels have been consistently under-projected in forecasts in many European countries (Alders et al. 2007).

Population growth

Changes in the size of a population produced by the surplus (or deficit) of births over deaths are termed natural increase (or decrease). A common indicator of growth is the crude rate of natural increase—the difference between the crude birth rate (annual births per 1000 population) and the crude death rate (annual deaths per 1000 population). If net migration is zero, this will be the same as the growth rate of the population—the overall annual change in the population divided by the population size—(conventionally expressed as a percentage). In several European countries deaths outnumbered births in the period 2005–2010, with the largest deficits in Ukraine, Bulgaria, Latvia, Belarus, Hungary, Lithuania, and the Russian Federation. In some others births still outnumber deaths even though fertility rates have been below the level required for *long-term* replacement for 40 years or so. This apparent paradox largely reflects the fact that the number of births is a function of the number of potential mothers, to which immigration may also contribute, as well as of their fertility patterns. If the former is increasing so too may the numbers of births, even if women have fewer children each.

The young age structures of many populations in the developing world mean that these populations have a huge built-in potential for growth. Population *momentum* is the measure which gives the ratio of the ultimate size a given population would achieve to current population size if fertility were to immediately fall to replacement level. Even allowing for the effect of HIV/AIDS-related mortality, the population of sub-Saharan Africa is expected to increase from 0.86 billion to 1.96 billion between 2010 and 2050 (UN 2011), a consequence of both population momentum and high levels of fertility. In some low-fertility countries there are now concerns about ‘negative momentum’—the prospect of decline in population even if fertility rates increase somewhat because of successively smaller cohorts of women in childbearing age groups.

Intrinsic rate of natural increase: stable population theory

Early in the twentieth century, Lotka (1907) demonstrated mathematically that a population closed to migration and subject to unchanging age-specific fertility and mortality rates for a long period would eventually have a fixed age structure (in which the proportion in each age group remained unchanged) and would grow at a constant rate. This type of population is called a *stable* population. The fixed age structure of a stable population is independent of the initial age structure—two very different populations subject to the same unchanging rates for a long period would eventually assume the same structure. A particular case of a stable population is a *stationary* population—one in which birth and death rates are constant and in balance and so population growth is zero. The L_x column of the life table is an example of a stationary population. The number of births is fixed (the radix) and the age distribution is also fixed. In non-stationary stable populations, the age structure is also fixed but the size of every age group is growing at the same constant rate as the overall population and the number of births. This is called the *intrinsic rate of natural increase* and is a function of the net reproduction rate and the mean length of a generation (approximated by the mean age of childbearing). Non-stationary stable populations can be calculated by adjusting the L_x values of a particular life table to allow for the intrinsic rate of growth. These are often published in conjunction with model life tables to show the effects of particular (unchanging) fertility and mortality regimes.

Although stable and stationary populations are theoretical constructs, real populations at various times have met the model requirements closely enough to allow stable population theory to be used to develop methods for indirectly estimating fertility and mortality in populations lacking adequate directly derived data. Stable population models are also widely used for insurance, pension, and personnel planning. One of the important results of the work of Lotka and his successors was to show theoretically the important influence of fertility on age structure.

Age structure

Population pyramids graphically illustrate the current structure of populations and in so doing, also provide insights into both the future and the past of the population. High fertility populations have a pyramid shape with each successive cohort being larger than its predecessor. The population pyramid for Bangladesh (Fig. **6.3.3A**) shows a typical pattern for a population with a history of high fertility but a recent downturn. Each successive cohort is larger than the preceding one, with the exception of the youngest. 'Old' populations, such as that of England and Wales (Fig. **6.3.3B**), are more rectangular with a gradual tapering at the top. Bulges in population pyramids due to high numbers of births have 'echo' effects when members of large cohorts themselves have children. Thus the baby boom experienced in many populations in the post-Second World War period (precise timing varied between countries) had an echo effect in the 1980s.

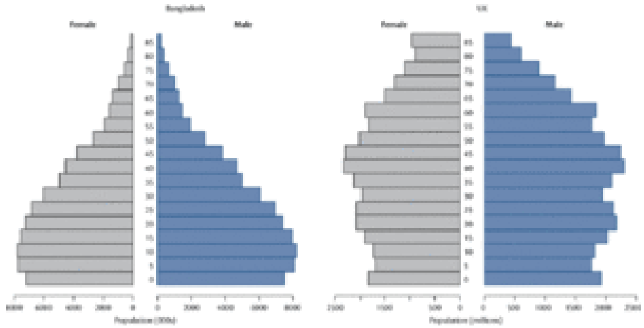

Fig. 6.3.3
Distribution of the population of (A) Bangladesh and (B) the UK by age and sex, 2010.

Source: data from United Nations, *World Population Prospects: The 2010 Revision*, United Nations, New York, USA, Copyright © 2012, available from http://esa.un.org/wpp/documentation/pdf/WPP2010_Volume-I_Comprehensive-Tables.pdf

Historically, and apparently paradoxically, improvements in mortality in those European populations which now have high proportions of old people in fact served to *offset* the trend towards population ageing, as they chiefly benefited the young—and led to increases in the proportions surviving to have children themselves. However, although fertility has the greatest *potential* impact on age structure and population growth, in some circumstances mortality (or migration) may become a more important influence. Many populations in richer countries now have fertility at or below replacement level, life expectancies at birth close to 80 and near universal survival to the end of the (female) reproductive span. In these conditions, further improvements in mortality have the greatest impact at old ages and further population ageing occurs from the apex, rather than, or in addition to, the base of the population pyramid. Mortality changes are now the main motor of the further ageing of a number of populations with already old age structures (Preston and Stokes 2012). Population age structures and associated rates of growth or decline, changes in age structures such as population ageing, and the speed and stage of age structural change all have important economic and health implications which have attracted considerable debate and controversy.

Many economists have pointed out that population growth has often provided a spur to human ingenuity and economic growth. Less positively, the countries which now have the youngest age structures and most rapid rates of population growth are already suffering from land degradation and in many cases, constrained agricultural potential (Alexandratos 2005). Large and growing child populations also hamper efforts at improving human capital through education or improved health (Casterline 2010).

Reduced fertility initially produces a ‘demographic dividend’ or ‘window’ when the ratio of children to adults falls and those in prime productive ages, the survivors of larger birth cohorts, account for a higher proportion of the population. It has been argued that this dividend of lower child dependency and higher representation of adults in the prime working age groups played an important part in the rapid economic development of the ‘East Asian Tigers’, like South Korea and also China (Bloom et al. 2000). The next phase, involving high and increasing representation of older people may, it has been suggested, also bring some economic benefit in the form of increased savings (by the large number of older people) and so greater capital available for investment (Mason and Lee 2006). However, population ageing is more often perceived as a challenge with potentially negative implications for both the economy and for population health (OECD 1999).

The major concerns arising from increases in the proportions of older people relate to effects on productivity and need for support systems of various kinds, including pensions, healthcare and long-term care. In OECD countries, healthcare expenditure is typically three to five times as high for those aged 65 and over as for those aged under 65. However there is considerable international variation in the proportion of GDP devoted to healthcare spending for older people which bears little obvious relationship to the proportion of older people in the population concerned.

In populations which have more recently moved to low fertility and low mortality regimes, the pace of demographic change has been much faster than occurred historically in Europe. The proportion of the Japanese population aged 65 and over doubled, from 7 per cent to over 14 per cent, between 1970 and 1996. In France a similar increase took 130 years to achieve and in Sweden 85 years (Kinsella and Phillips 2005). More recently ageing populations have thus had a much shorter period in which to adapt to new public health priorities. The origins of these age structure changes lie in the demographic transition.

The demographic transition

Towards the end of the nineteenth century (earlier in France) birth and death rates started falling in a number of European countries. Between 1871–1875 and 1911–1915 the TFR for England and Wales, for example, dropped from 4.8 to 2.8; by the early 1930s it was below replacement level, a development which was viewed with alarm and led to the first Royal Commission on Population. Although modern methods of contraception were lacking, it was clear that this huge drop in fertility was the result of the deliberate limitation of family size. Half of couples married in the 1870s had six or more children compared with 12 per cent of couples married in 1911–1915 (Coleman and Salt 1992). Expectation of life at birth, meanwhile, increased by some 15 years between the end of the nineteenth century and the early 1930s.

Researchers attempting to relate such shifts in demographic regimes to economic and social changes, originated the theory of the demographic transition. The ‘classical’ view propounded by Notestein (1945) and others was that in ‘traditional’ societies fertility and mortality are both high and roughly in balance. Change is driven by economic advance which results in lower mortality. Fertility initially remains high, resulting in a rapid period of population growth. After this lag, however, fertility also falls in response to falling mortality and the erosion of ‘traditional’ pro-natalist values.

This classical view has since been considerably modified (Lee 2003). Coale and his collaborators in an ambitious project to track the transition in historical Europe suggested that no economic ‘threshold’ for fertility decline could be identified and that the pattern of decline seemed to follow regional groupings, suggesting a cultural rather than a socioeconomic dimension (Coale and Watkins 1986). Falls in infant mortality, assumed to be a particularly important stimulus to fertility decline, sometimes followed rather than preceded changes in fertility. For example, Woods et al. (1989) argued that declines in fertility led to reductions in infant mortality, rather than vice versa in England and Wales. In short, the role of mortality decline as a trigger and the dominance of economic change have both been questioned. Caldwell (1982) additionally argued that in non-European countries, it was not so much socioeconomic modernization but 'Westernization' involving increased emphasis on the nuclear family and a change in intergenerational wealth flows (resulting in the costs of children outweighing their potential benefits) that was the important trigger of fertility transition.

Research on the historical demographic transition in Europe may seem of limited relevance to contemporary problems. However, this research was fuelled by post-war fears about population growth. By 1950, significant mortality declines had been achieved or initiated throughout the world. In China, for example, expectation of life at birth increased from 43 in 1960 to over 75 by 2010. Even in sub-Saharan Africa, a gain of nearly 10 years—from 43 to 52—was achieved between 1950 and 1990, sadly since reversed although now starting to increase again (World Bank 1993; UN 2011). In this context it seemed imperative to discover the causes of fertility decline and use this knowledge to accelerate fertility 'adjustment' to falling mortality. Was 'development the best contraceptive' as concluded at the stormy 1974 World Population Conference; could change be achieved through intensive family planning programmes, as the experience in Taiwan and South Korea seemed to suggest; or was some combination of these and other factors the key to fertility transition? Studies of societies in which the fertility transition had occurred seemed to offer the best prospect of an answer to these questions. While simple answers to complex questions are rarely forthcoming, Coale (1973) identified three factors which he considered prerequisites for fertility decline in contemporary populations. These were: that potential parents must think it acceptable to balance the advantages and disadvantages of another child, that some advantage must be gained from reduced fertility, and that effective techniques of fertility control must be available.

Trends in fertility in the second half of the last century and early part of this century have shown considerable divergence and shed some light on these debates. TFRs are highest in sub-Saharan Africa, with Uganda, Somalia, Mali, Timor-Leste, and Niger having TFRs above 6.3 in 2005–2010. In all other world regions there was clear evidence of onset of a transition to lower fertility by the 1970s or 1980s; Japan was the first non-Western country to experience a fertility transition starting after the Second World War. Globally, the estimated TFR in 2005–2010 was 2.52, with 48 per cent of the world population living in countries with below-replacement fertility levels (UN 2011). Substantial fertility declines have occurred in a number of countries which at that time had only a limited amount of development, such as Sri Lanka, Thailand, China, and more recently Bangladesh. One of the largest and fastest fertility declines took place in the Islamic Republic of Iran where fertility fell from 7.0 in 1980 to 1.9 in 2006 (Abbasi-Shavazi et al. 2009) defying assumptions that socially and religiously conservative Muslim societies with low rates of female employment would be resistant to fertility change.

Recent interpretations of fertility change have reverted to considering development—in its broadest sense rather than restricted to consideration of average incomes—a stronger influence in contemporary populations than ideational changes, although the relevance and role of cultural and policy related factors is recognized (Bryant 2007). Common factors identified in poor rural populations where fertility has fallen significantly are well-established education systems, improvements in healthcare and in child survival, some form of extra-familial welfare, well-organized local government, and an organized family planning programme. Potential benefits of investing more resources in fewer children, as a consequence of increasing opportunities in urban or industrial livelihoods, also seem to be important

(McNicoll 2006; Bryant 2007). The education of women has been identified as a particularly significant influence on both falling fertility and improved infant survival (Cleland 1990; Hobcraft 1993) and female education and empowerment were recognized as key policy objectives at the 1994 International Conference on Population and Development (UNFPA 1995).

As noted earlier, fertility rates remain high in much of sub-Saharan Africa. Continuing expressed preferences for large families and other family and social characteristics of African populations have led some to conclude that the model of change seen in Asia and Latin America may not be applicable to Africa, or at least not to all regions of Africa (Caldwell et al. 1992). There is nevertheless evidence of unmet demand for family planning and a strong case can be made, on the grounds of improving maternal and child health, for renewed investment in family programmes which in some places faltered as the policy focus and funding shifted to the HIV/AIDs crisis (Cleland et al. 2006).

Recent trends have also made it clear that the end point of fertility transition is not necessarily a fertility level around the ‘replacement rate’. In some countries, such as Guatemala, Peru, Egypt, Turkey and Ghana, fertility declines ‘stalled’ (sometimes temporarily) at a level higher than two children per woman (Bongaarts 2005). In others they have continued downward spiralling, giving rise to a new set of concerns about ‘lowest low’ fertility.

Lowest low fertility and the second demographic transition

In contrast to the scenario of high fertility and rapid population growth in some of the poorest countries, a growing number of high-income countries now have concerns about the implications of low fertility. Many of these countries experienced a post-Second World War ‘baby boom’ during the 1950s and early 1960s followed by a 1970s ‘baby bust’ when fertility declined to very low levels. In Scandinavia, France, the United Kingdom, the United States, and other English-speaking countries fertility rates have since fluctuated at levels between 1.6 and replacement level with something of an increase in the first decade of this century—a pattern also seen in many other industrialized countries—however, this may turn out to be a temporary phenomenon particularly given current economic conditions. These populations have also experienced a range of family-related behavioural changes, included marked increases in cohabitation, non-marital childbearing, divorce, postponed childbearing, and increased levels of childlessness, described by some as a ‘Second Demographic Transition’ (Lesthaeghe and Neidert 2006). Such behaviours, which have become more usual among Northern European cohorts born from around the 1950s onwards, are much less prominent in Southern and Eastern Europe and the richer countries of South and East Asia. However, it is mainly in these latter countries that ‘lowest low’ fertility—rates below 1.3—has been prevalent with 21 countries from these regions having TFRs below 1.3 in 2003 (Goldstein et al. 2009). The recent increase in fertility in developed societies meant that only three of these countries, South Korea, Slovakia, and Singapore, had average values below 1.3 in the period 2005–2010 (UN 2011). However, the TFR remained below 1.5 in a large number of other countries including Poland, Japan, Germany, Italy, Ukraine, Spain, and the Russian Federation in 2005–2010. An important determinant of very low fertility in many of these societies has been a precipitous fall in marriage rates (Billari and Kohler 2004). Japan, for example, has been transformed from a society with near universal marriage in the early and mid twentieth century to one in which a fifth of the population will remain never-married at age 45 (Retherford et al. 2001). In this case the erosion of arranged marriages after the Second World War has played a part; changing gender roles may also be important. In some countries with very low fertility, explicit pro-natalist polices are under discussion or have been introduced, however these remain controversial and of unclear effectiveness.

The proximate determinants of fertility

One of the contributions of research into the fertility transition has been improved understanding of biosocial influences on reproduction. A huge range of social, economic, cultural, and psychological factors may influence decisions about family building strategies and family size. However, these can only have effect if they are translated into patterns of behaviour or physiological characteristics that influence the risks of conception or delivery.

Conversely, other patterns of behaviour with potentially important influences on fertility may be adopted with little or no thought to these consequences. Davis and Blake (1956) distinguished a series of ‘intermediate fertility variables’: factors influencing exposure to risk of pregnancy (marriage and coital frequency), risk of pregnancy (such as contraception), and pregnancy outcome (spontaneous and induced abortion). The most influential refinement of this work is the Bongaarts decomposition model (Bongaarts 1978), which identified four elements chiefly responsible for observed fertility variations:

- The proportion of women married (exposed to risk).
- Contraceptive use.
- Induced abortion.
- Post-partum non-susceptibility to conception (largely determined by breastfeeding practice).

The TFR is dependent on the interactive effect of these variables and hypothetical maximum fertility. In modern ‘post-transition’ populations, fertility decisions are normally couple- (or woman-) based and are implemented through contraception and abortion. In non-contracepting populations, biosocial factors, notably marriage patterns, breastfeeding practices, sexual frequency and, in some populations, the prevalence of infertility, are of major importance.

The social reproductive span, from entry to end of marriage or any sexual union, nearly always starts later, often much later, than menarche. Fecundity—the potential for bearing children—decreases after the third decade, more sharply after the age of 35 and in most non-contracepting populations the average age at last birth is around 40. Social factors, as well as biological ones, are important influences. Sexual activity may cease before menopause because of widowhood or separation. In some African populations, childbearing after becoming a grandmother is disapproved of.

For those within the effective reproductive span—biologically capable of childbearing and in a sexual union—overall fertility is largely a function of length of intervals between births, itself largely determined by breastfeeding patterns. Among non-breastfeeding women, average duration of post-partum amenorrhea is only 1.5–2 months, compared with 18 months or more with protracted breastfeeding, particularly in some populations where sexual activity is proscribed for breastfeeding mothers.

Longer birth intervals and increased breastfeeding also have positive effects on infant and child health. Overall deaths before the age of 5 might be reduced by as much as 30 per cent in some countries if closely spaced births were delayed (World Bank 1993; Cleland et al. 2006).

The epidemiological transition

Transitions from relatively high- to low-mortality regimes have in all populations been associated with transformations in the age, cause, and sex structure of death. Omran (1971) coined the phrase 'epidemiological transition' to describe this process. Changes in the response of societies to health and disease processes also need consideration. The term 'health transition' has been proposed as one which embraces both these phenomena.

Substantial falls in death rates from infectious and parasitic diseases and maternal mortality are hallmarks of the epidemiological transition. In England and Wales, over half the gain in life expectancy at birth between 1871 and 1911 was due to reduced infectious disease mortality. Some 20 per cent of the total gain was due to reduced death rates from tuberculosis (Caselli 1991). Declines in these causes of death were greater among the young, hence deaths at older ages accounted for a larger share of all deaths; the epidemiological transition has also been consistently associated with larger falls in mortality among women than men. Changes in the intra-household allocation of resources, declines in causes of death primarily affecting women (such as maternal mortality and respiratory tuberculosis), gender differences in health-related behaviour and in exposure to occupational hazards, and the possibly greater susceptibility of men to stresses associated with socioeconomic changes, may all be underlying factors.

The relative contribution of various eighteenth- and nineteenth- century developments in promoting the historical epidemiological transition in the West remains a matter of debate. Improved nutrition, better housing and living conditions, public sanitation schemes, and specific public health initiatives, such as smallpox inoculation, all have their adherents. In the early twentieth century, improved personal hygiene practices and better infant care were also important. A common thread linking most of these factors is their relationship to overall social and economic development and improvements in standards of living. During the twentieth century, however, developments in medical technology and vector control offered the potential for 'exogenous' mortality decline less dependent on a particular country's level of income and development. One consequence was that the relationship between per capita income and life expectancy has shifted to the right (Preston 1975, 2007). In 1901, for example, life expectancy in the United States was 49 and income per capita was about US$7300 (2005 purchasing power parity). In 2009, income per capita in China was almost identical ($7400) but life expectancy was 73 years (http://www.gapminder.org/).

Many poor countries have been able to achieve remarkable falls in mortality, especially child mortality, through behavioural change, improved education of women, and introduction of relatively cheap treatments and interventions, such as vaccination and antibiotics (Cutler et al. 2006). Between 1975–1980 and 2005–2010 life expectancy at birth increased from 53 to 68 in Bangladesh and from 56 to 68 in Indonesia (UN 2011) and there are now a number of poor or middle-income countries with life expectancies at birth as high as in the United States.

The process of the epidemiological transition (or at least the initial phases) is now complete or under way in much of the world and non-communicable causes of death predominate in all regions except sub-Saharan Africa (see Table 6.3.2). However, some recent changes have been less benign and new challenges or reversals have emerged, notably the HIV/AIDS epidemic and the health consequences of the collapse of the former Soviet Union (Olshansky et al. 1997; Murphy 2011). Partly because of these challenges, there are signs that after a period in which risks of mortality in different parts of the world showed a tendency to converge (i.e. poorer countries caught up with richer ones), more recently there has been a trend towards divergence. Another factor in this may be that recent successes in richer countries in, for example, lowering mortality from heart disease, have partly been achieved through treatments which are harder to 'transfer' to poor countries because of infrastructure and cost limitations (Vallin and Mesle 2004; Ford et al. 2007).

Recent demographic trends and public health

Population size, growth, and age structure are all outcomes of variations in demographic behaviours and all have implications for population health and well-being. Population ageing will almost certainly be the predominant demographic issue of the twenty-first century in nearly all richer and a growing number of poorer countries. The strong association between age and risks of health impairment and disability imply growing needs for support services, even if levels of disability fall. In those countries which are growing old before they grow rich, changes in family support systems for older people may pose additional challenges. A range of strategies for responding to these challenges has been proposed, including encouraging longer working lives through review of retirement and pensions policies, better organization of acute and long-term care services, and initiatives to promote healthy ageing (Rechel et al. 2013).

Changes in marriage and family patterns also have other public health implications. In North America and North West Europe (and also Latin America and the Caribbean) high rates of divorce and non-marital childbearing mean that increasing proportions of children are spending at least part of their childhood in lone-parent families. Although causal pathways are difficult to elucidate because of various selection effects, there is evidence indicating poorer health among lone mothers and their children, and among unmarried (especially divorced) people more generally, so these trends have some negative implications.

Continuing improvement in child and adult mortality is projected for the poorer world, based on optimistic assumptions about the course of the HIV/AIDS epidemic. In the poorest countries the interaction of rapid population growth, environmental degradation and conflict pose continuing health problems and the 'unfinished agenda' in terms of health includes providing access to contraception for women who wish to space or limit their children (Cleland et al. 2006). In other middle- and low-income countries, patterns of tobacco use are likely to have a substantial effect on health trends in coming decades (West 2006).

Issues such as international migration, economic and cultural 'globalization', and climate change all have substantial health implications for the rest of the twenty-first century; all interact with demographic patterns and processes. Measuring these trends and assessing their effect on health and demand for healthcare requires an understanding of population dynamics and population-based measures, and suitable demographic data. Demography is thus an essential component of public health.

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